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NFPA 12
Carbon Dioxide Extinguishing Systems
1989 Edition

NFPA

National Fire Protection Association Batterymarch Park, Quincy, MA 02269

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Policy Adopted by NFPA Board of Directors on December 3, 1982

The Board of Directors reaffirms that the National Fire Protection Association recognizes that the toxicity of the products of combustion is an important factor in the loss of life from fire. NFPA has dealt with that subject in its technical committee documents for many years.

There is a concern that the growing use of synthetic materials may produce more or additional toxic products of combustion in a fire environment. The Board has, therefore, asked all NFPA technical committees to review the documents for which they are responsible to be sure that the documents respond to this current concern. To assist the committees in meeting this request, the Board has appointed an advisory committee to provide specific guidance to the technical committees on questions relating to assessing the hazards of the products of combustion.

Statement on NFPA Procedures

This material has been developed under the published procedures of the National Fire Protection Association, which are designed to assure the appointment of technically competent Committees having balanced representation. While these procedures assure the highest degree of care, neither the National Fire Protection Association, its members, nor those participating in its activities accepts any liability resulting from compliance or noncompliance with the provisions given herein, for any restrictions imposed on materials or processes, or for the completeness of the text.

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NATIONAL FIRE PROTECTION ASSOCIATION

NFPA 12

Standard on

Carbon Dioxide Extinguishing Systems

1989 Edition

This edition of NFPA 12, *Standard on Carbon Dioxide Extinguishing Systems*, was prepared by the Technical Committee on Carbon Dioxide, and acted on by the National Fire Protection Association, Inc. at its Fall Meeting held November 14-17, 1988 in Nashville, Tennessee. It was issued by the Standards Council on January 13, 1989, with an effective date of February 6, 1989, and supersedes all previous editions.

The 1989 edition of this document has been approved by the American National Standards Institute.

Changes other than editorial are indicated by a vertical rule in the margin of the pages on which they appear. These lines are included as an aid to the user in identifying changes from the previous edition.

Origin and Development of NFPA 12

Work on this standard was initiated in 1928 by the then Committee on Manufacturing Risks and Special Hazards. The standard was first adopted in 1929 and was revised in 1933, 1939, 1940, 1941, 1942 (January and May), 1945, 1946, 1948, 1949, 1956, 1957, 1961, 1962, 1963, 1964, 1966, 1968, 1972, 1973, 1977, and 1980. Revisions adopted 1945-1949 were proposed by the Committee on Special Extinguishing Systems, and those in 1956 and subsequently were proposed by the Committee on Carbon Dioxide. The standard was revised in 1985 and 1989.

Technical Committee on Carbon Dioxide

Elmer M. Wetmore, *Chairman*
Kemper Group

Charles B. Ford, *Secretary*
Queenstown, MD
(Rep NAFED)

Kerry Bell, Underwriters Laboratories Inc.
Joel I. Dumont, Aluminum Co. of America
Brent S. Ehmke, The Ansul Co.
Rep. FEMA
William T. Fleming, Walter Kidde
Rep. CGA
Edward D. Leedy, Industrial Risk Insurers
Norbert W. Makowka, Reliable Fire Equipment Co.
Robert C. Merritt, Factory Mutual Research Corp.
Paul Rockwell, Fox Valley Fire & Safety Co.
Rep. FSSA
James M. Rucci Jr., Duke Power Co.
Rep. EEI
Bruce G. Scheiman, Chemetron Fire Systems
D. R. Todd, Levitt-Safety Ltd.
Rep. FEMI of Canada
Gregory G. Wilks, M&M Protection Consultants
H. V. Williamson, Roscoe, IL
Robert Worthington, Globe Fire Equipment Co.
(Rep. NFSA)

Thomas J. Wysocki, NF Fire Control Systems

Alternates

Robert K. Andrews, M&M Protection Consultants
(Alternate to G. G. Wilks)
Ezio Angelini, Automatic Sprinker Corp. of Am.
(Alternate to R. Worthington)
William M. Carey, Underwriters Laboratories Inc.
(Alternate to K. Bell)
Salvatore A. Chines, Industrial Risk Insurers
(Alternate to E. D. Leedy)
Tim Meyer, Kemper Group
(Alternate to E.M. Wetmore)
Earl D. Neargarth, Ansul Fire Protection
(Alternate to B. S. Ehmke)
Wayne Rives, C-O-Two Fire Equipment Co.
(Alternate to C. Ford)
Don J. Slee, Compressed Gas Assn. Inc.
(Alternate to W. T. Fleming)

Mark Conroy, NFPA Staff Liaison

This list represents the membership at the time the Committee was balloted on the text of this edition. Since that time, changes in the membership may have occurred.

NOTE: Membership on a Committee shall not in and of itself constitute an endorsement of the Association or any document developed by the Committee on which the member serves.

Contents

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Carbon Dioxide Extinguishing Systems

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates explanatory material on that paragraph in Appendix A.

Information on referenced publications can be found in Chapter 6 and Appendix C.

Chapter 1 General Information and Requirements

1-1 Scope. This standard contains minimum requirements for carbon dioxide fire extinguishing systems. It includes only the necessary essentials to make the standard workable in the hands of those skilled in this field.

NOTE: Portable carbon dioxide equipment is covered in NFPA 10, *Standard for Portable Fire Extinguishers*. The use of carbon dioxide for inerting is covered in NFPA 69, *Standard on Explosion Prevention Systems*.

1-2 Purpose. This standard is prepared for the use and guidance of those charged with the purchasing, designing, installing, testing, inspecting, approving, listing, operating, or maintaining of carbon dioxide fire extinguishing systems, in order that such equipment will function as intended throughout its life. Nothing in this standard is intended to restrict new technologies or alternate arrangements provided the level of safety prescribed by the standard is not lowered.

1-2.1 Only those skilled in the field are competent to design and install this equipment. It may be necessary for many of those charged with the purchasing, inspecting, testing, approving, operating, and maintaining of this equipment to consult with a competent fire protection engineer experienced in carbon dioxide system work in order to effectively discharge their respective duties.

1-3 Arrangement. This standard is arranged as follows:

Chapter 1 — General Information and Requirements.

Chapter 2 — Total Flooding Systems.

Chapter 3 — Local Application Systems.

Chapter 4 — Hand Hose Line Systems.

Chapter 5 — Standpipe Systems and Mobile Supply.

Chapter 6 — Referenced Publications.

Appendix A — Explanatory.

Appendix B — Examples of Hazard Protection.

Appendix C — Referenced Publications.

Chapters 1 through 6 constitute the body of the standard and contain the rules and regulations necessary for properly designing, installing, inspecting, testing, approving, operating, and maintaining carbon dioxide fire extinguishing systems.

The Appendices contain educational and informative material that will aid in understanding and applying this standard.

1-4 Definitions and Units.

1-4.1 Definitions. For purposes of clarification, the following general terms used with special technical meanings in this standard are defined:

Approved. Acceptable to the "authority having jurisdiction."

NOTE: The National Fire Protection Association does not approve, inspect or certify any installations, procedures, equipment, or materials nor does it approve or evaluate testing laboratories. In determining the acceptability of installations or procedures, equipment or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization concerned with product evaluations which is in a position to determine compliance with appropriate standards for the current production of listed items.

Authority Having Jurisdiction. The "authority having jurisdiction" is the organization, office or individual responsible for "approving" equipment, an installation or a procedure.

NOTE: The phrase "authority having jurisdiction" is used in NFPA documents in a broad manner since jurisdictions and "approval" agencies vary as do their responsibilities. Where public safety is primary, the "authority having jurisdiction" may be a federal, state, local or other regional department or individual such as a fire chief, fire marshal, chief of a fire prevention bureau, labor department, health department, building official, electrical inspector, or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the "authority having jurisdiction." In many circumstances the property owner or his designated agent assumes the role of the "authority having jurisdiction"; at government installations, the commanding officer or departmental official may be the "authority having jurisdiction."

High Pressure. Indicates that the carbon dioxide is stored in pressure containers at atmospheric temperatures. At 70 °F (21 °C), the pressure in this type of storage is 850 psi (58.6 bars).

Inspection. A visual observation to ensure that:

(a) all components are in position in good condition and connected to the system,

(b) The system is installed in accordance with the latest installation drawings and design specifications,

(c) The hazard conforms to the dimensional envelope to which the system was designed,

(d) A check for proper designation and instructions has been made. (*See Section 1-11.*)

Labeled. Equipment or materials to which has been attached a label, symbol or other identifying mark of an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Listed. Equipment or materials included in a list published by an organization acceptable to the "authority having jurisdiction" and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials and whose listing states either that the equipment or material meets appropriate standards or has been tested and found suitable for use in a specified manner.

NOTE: The means for identifying listed equipment may vary for each organization concerned with product evaluation, some of which do not recognize equipment as listed unless it is also labeled. The "authority having jurisdiction" should utilize the system employed by the listing organization to identify a listed product.

Low Pressure. Indicates that the carbon dioxide is stored in pressure containers at controlled low temperatures, at 0 °F (−18 °C). At 0 °F (−18 °C), the pressure in this type of storage is 300 psi (20.7 bars).

Maintenance. A "thorough check" of the system, intended to give maximum assurance that the system will operate effectively and safely. It includes a thorough examination and any necessary repair or replacement of components. (*See Section 1-11.*)

Shall. Indicates a mandatory requirement.

Should. Indicates a recommendation or that which is advised but not required.

1-4.2 Units. Metric units of measurement in this standard are in accordance with the modernized metric system known as the International System of Units (SI). The unit bar is outside of but recognized by SI, and is commonly used in international fire protection. The unit is listed in Table 1-4.2 with conversion factors.

Table 1-4.2

Name of Units	Unit Symbol	Conversion Factor
pascal	Pa	1 psi = 6894.757 Pa
bar	bar	1 psi = 0.0689 bar
bar	bar	1 bar = 10^5 Pa
kilogram	kg	1 pound = 2.205 kg
meters	m	1 ft = 0.3048 m
millimeters	mm	1 in. = 25.4 mm

For additional conversions and information see ASTM E380, *Standard for Metric Practice*.

1-4.2.1 If a value for measurement as given in this standard is followed by an equivalent value in other units, the first stated is to be regarded as the requirement. A given equivalent value may be approximate.

1-4.2.2 The conversion procedure for the SI units has been to multiply the quantity by the conversion factor and then round the result to the appropriate number of significant digits.

1-5 General Information and Requirements.

1-5.1 Chapter 1 contains general information and the design and installation requirements for all features that are generally common to all carbon dioxide systems.

1-5.2* Carbon Dioxide. Carbon dioxide is a colorless, odorless, electrically nonconductive inert gas that is a suitable medium for extinguishing fires. Liquid carbon dioxide forms dry ice snow when released directly into the atmosphere. Carbon dioxide gas is 1.5 times heavier than air. Carbon dioxide extinguishes fire by reducing the concentrations of oxygen, the vapor phase of the fuel or both in the air to the point where combustion stops.

1-5.2.1 Carbon dioxide is present in the atmosphere at an average concentration of about 0.03 percent by volume. It is also a normal end product of human and animal metabolism. Carbon dioxide influences certain vital functions in a number of important ways, including control of respiration, dilation, and constriction of the vascular system — particularly the cerebrum — and the pH of body fluids. The concentration of carbon dioxide in the air governs the rate at which carbon dioxide is released from the lungs and thus affects the concentration of carbon dioxide in the blood and tissues. An increasing concentration of carbon dioxide in air can, therefore, become dangerous due to a reduction in the rate of release of carbon dioxide from the lungs and decreased oxygen intake. [Further details of carbon dioxide exposure can be obtained from HEW (NIOSH) Publication No. 76-194 listed in Appendix C]. Personnel safety considerations are covered in Section 1-6.

1-5.3 Use and Limitations. Carbon dioxide fire extinguishing systems are useful within the limits of this standard in extinguishing fires in specific hazards or equipment, and in occupancies where an inert electrically nonconductive medium is essential or desirable, where cleanup of other media presents a problem, or where they are more economical to install than systems using other media.

1-5.3.1 All areas or parts of a hazard to which or from which a fire may spread shall be simultaneously protected.

1-5.3.2 Some of the more important types of hazards and equipment that carbon dioxide systems may satisfactorily protect include:

(a) Flammable liquid materials. (*See 1-8.3.8.*)

CAUTION: Gas fires should normally be extinguished by shutting off the gas flow. Extinguishing the gas flame with carbon dioxide may be desirable where necessary to permit immediate access to valves to shut off the gas supply. Extinguishment of gas fires indoors with carbon dioxide may create an explosion hazard and is not recommended.

(b) Electrical hazards, such as transformers, oil switches and circuit breakers, rotating equipment, and electronic equipment.

(c) Engines utilizing gasoline and other flammable liquid fuels.

(d) Ordinary combustibles such as paper, wood, and textiles.

(e) Hazardous solids.

1-5.3.3 The discharge of liquid carbon dioxide is known to produce electrostatic charges which, under certain conditions, could create a spark. Carbon dioxide fire extinguishing systems protecting areas where explosive atmospheres could exist shall utilize metal nozzles and shall be properly grounded. In addition, objects exposed to discharge from carbon dioxide nozzles shall be grounded to dissipate possible electrostatic charges (*see NFPA 77, Recommended Practice on Static Electricity*).

1-5.3.4* Carbon dioxide will not extinguish fires where the following materials are actively involved in the combustion process:

(a) Chemicals containing their own oxygen supply, such as cellulose nitrate.

(b) Reactive metals such as sodium, potassium, magnesium, titanium, and zirconium.

(c) Metal hydrides.

1-5.4 Types of Systems. There are four types of systems recognized in this standard:

Total Flooding Systems.

Local Applicaton Systems.

Hand Hose Line Systems.

Standpipe Systems and Mobile Supply.

1-5.4.1 A Total Flooding System consists of a fixed supply of carbon dioxide normally connected to fixed piping with nozzles arranged to discharge carbon dioxide into an enclosed space or enclosure around the hazard.

1-5.4.2 A Local Application System consists of a fixed supply of carbon dioxide normally connected to fixed piping with nozzles arranged to discharge carbon dioxide directly on the burning material.

1-5.4.3 A Hand Hose Line System consists of a fixed supply of carbon dioxide supplying hose lines.

1-5.4.4 A Standpipe System and Mobile Supply consists of a mobile supply of carbon dioxide capable of being quickly moved into position and connected to a system of fixed piping supplying fixed nozzles or hose lines or both that may be used for either total flooding or local application.

1-5.5 Carbon Dioxide System. A carbon dioxide system may be used to protect one or more hazards or groups of hazards by means of directional valves (with the permission of the authority having jurisdiction). Where two or more hazards may be simultaneously involved in fire by reason of their proximity, each hazard shall be either (1) protected with an individual system, with the combination arranged to operate simultaneously, or (2) protected with a single system that shall be sized and arranged to discharge on all potentially involved hazards simultaneously.

1-5.6 Package Systems (Kits). Package systems consist of system components designed to be installed according to pretested limitations as approved or listed by a testing laboratory.

1-5.6.1 Package systems may incorporate special nozzles, flow rates, methods of application, nozzle placement, and quantities of carbon dioxide which may differ from those detailed elsewhere in this standard since they are designed for very specific hazards. All other requirements of the standard apply.

1-5.6.2 Package systems shall be installed to protect hazards within the limitations which have been established by the testing laboratories where listed.

1-6* Personnel Safety.

1-6.1 Hazards to Personnel. The discharge of carbon dioxide in fire extinguishing concentration creates serious hazards to personnel, such as suffocation and reduced visibility during and after the discharge period. Consideration shall be given to the possibility of carbon dioxide drifting and settling into adjacent places outside of the protected space (*see 1-5.2*). Consideration shall also be given to where the carbon dioxide may migrate or collect in event of a discharge from a safety relief device of a storage container.

1-6.1.1 Warning Signs. Appropriate warning signs shall be affixed outside of those spaces where concentrations of carbon dioxide gas can accumulate, not only in protected spaces but in adjacent areas where the carbon dioxide could migrate. Typical signs are shown below:

Typical sign in protected space:

WARNING
CARBON DIOXIDE GAS
WHEN ALARM OPERATES
VACATE IMMEDIATELY

Typical sign at entrance to protected space:

WARNING
CARBON DIOXIDE GAS
WHEN ALARM OPERATES DO NOT
ENTER UNTIL VENTILATED

Typical sign in nearby space:

CAUTION
CARBON DIOXIDE DISCHARGE INTO A
NEARBY SPACE MAY COLLECT HERE
WHEN ALARM OPERATES
VACATE IMMEDIATELY

Appropriate warning signs shall be placed at every location where manual operation of the system may occur. A typical sign at each manual actuation station:

WARNING
ACTUATION OF THIS DEVICE WILL CAUSE
CARBON DIOXIDE TO DISCHARGE.
BEFORE ACTUATING, BE SURE PERSONNEL
ARE CLEAR OF THE AREA.

1-6.1.2 In any use of carbon dioxide, consideration shall be given to the possibility that personnel could be trapped in or enter into an atmosphere made hazardous by a carbon dioxide discharge. Suitable safeguards shall be provided to ensure prompt evacuation to prevent entry into such atmospheres and provide means for prompt rescue of any trapped personnel. Personnel training shall be provided. Predischarge alarms shall be provided except as noted in 1-8.1(c) and 1-8.3.5.

NOTE: It is recommended that self-contained breathing apparatus be provided for rescue purposes.

1-6.1.3 All persons that may at any time enter a space protected by carbon dioxide shall be warned of the hazards involved.

NOTE: Personnel trained to recognize the alarm signal may be needed to warn persons who enter the space and aid in safe evacuation. (*See 1-8.5.*)

1-6.1.4 The predischarge warning signal shall provide a time delay of sufficient duration to allow for evacuation under "worst case" conditions, except as noted in 1-8.1(c) and 1-8.3.5. Dry runs shall be made to determine the minimum time that shall be allowed for persons to remove themselves from the hazard area after allowing time to identify the warning signal.

1-6.1.5 Audible predischarge signals shall be provided. Visual signals shall be provided if the ambient noise level is high, or if persons with hearing impairment are involved, except as noted in 1-8.1(c) and 1-8.3.5.

1-6.1.6 All personnel must be acquainted with the fact that discharge of carbon dioxide gas from either high or low pressure systems directly at a person may endanger their safety by eye injury, ear injury, or even falls due to loss of balance on the impingement of the high velocity discharging gas. Contact with carbon dioxide in the form of dry ice can cause frostbite.

1-6.1.7 To prevent accidental or deliberate discharge, a "lock-out" shall be provided when persons not familiar with the systems and their operation are present in a protected space. When protection is to be maintained during the lock-out period, a person(s) shall be assigned as a "fire watch" with suitable portable or semiportable fire fighting equipment, or means to restore protection. The "fire watch" shall have a communication link to a constantly monitored location. Authorities responsible for continuity of fire protection shall be notified of lock-out and subsequent restoration of the system.

1-6.2 Electrical Clearances. All system components shall be so located as to maintain minimum clearances from live parts as shown in Table 1-6.2.

As used in this standard, "clearance" is the air distance between equipment, including piping and nozzles, and unenclosed or uninsulated live electrical components at other than ground potential. The minimum clearances listed in Table 1-6.2 are for the purpose of electrical clearance under normal conditions; they are not intended for use as "safe" distances during fixed system operation.

The clearances given are for altitudes of 3,300 ft (1000 m) or less. At altitudes in excess of 3,300 ft (1000 m) the clearance shall be increased at the rate of 1 percent for each 330-ft (100-m) increase in altitude above 3,300 ft (1000 m).

The clearances are based upon minimum general practices related to design Basic Insulation Level (BIL) values. To coordinate the required clearance with the electrical design, the design BIL of the equipment being protected shall be used as a basis, although this is not material at nominal line voltages of 161 kv or less.

Up to electrical system voltages of 161 kv, the design BIL kv and corresponding minimum clearances, phase to ground, have been established through long usage.

At voltages higher than 161 kv, uniformity in the relationship between design BIL kv and the various electrical system voltages has not been established in practice. For these higher system voltages it has become common practice to use BIL levels dependent on the degree of protection which is to be obtained. For example, in 230-kv systems, BILs of 1050, 900, 825, 750, and 650 kv have been utilized.

Required clearance to ground may also be affected by switching surge duty, a power system design factor which along with BIL must correlate with selected minimum clearances. Electrical design engineers may be able to furnish clearances dictated by switching surge duty. Table 1-9 deals only with clearances required by design BIL. The selected clearance to ground shall satisfy the greater of switching surge or BIL duty, rather than be based upon nominal voltage.

Table 1-6.2
Clearance from Carbon Dioxide Equipment to Live Uninsulated Electrical Components

Nominal System Voltage (kv)	Maximum System Voltage (kv)	Design BIL (kv)	Minimum* Clearance (in.)	(mm)
To 13.8	14.5	110	7	178
23	24.3	150	10	254
34.5	36.5	200	13	330
46	48.3	250	17	432
69	72.5	350	25	635
115	121	550	42	1067
138	145	650	50	1270
161	169	750	58	1473
230	242	900	76	1930
		1050	84	2134
345	362	1050	84	2134
		1300	104	2642
500	550	1500	124	3150
		1800	144	3658
765	800	2050	167	4242

*For voltages up to 161 kv the clearances are taken from NFPA 70, *National Electrical Code*®. For voltages 230 kv and above the clearances are taken from Table 124 of ANSI C-2, *National Electrical Safety Code*.

NOTE: BIL values are expressed as kilovolts (kv), the number being the crest value of the full wave impulse test that the electrical equipment is designed to withstand. For BIL values which are not listed in the table, clearances may be found by interpolation.

Possible design variations in the clearance required at higher voltages are evident in the table, where a range of BIL values is indicated opposite the various voltages in the high voltage portion of the table. However, the clearance between uninsulated energized parts of the electrical system equipment and any portion of the carbon dioxide system shall be not less than the minimum clearance provided elsewhere for electrical system insulations on any individual component.

1-6.2.1 When the design BIL is not available, and when nominal voltage is used for the design criteria, the highest minimum clearance listed for this group shall be used.

1-7 Specifications, Plans, and Approvals.

1-7.1 Purchasing Specifications. Specifications for carbon dioxide fire extinguishing systems shall be drawn up with care and with the advice of the authority having jurisdiction.

1-7.1.1 The specifications shall designate the authority having jurisdiction and describe the hazard.

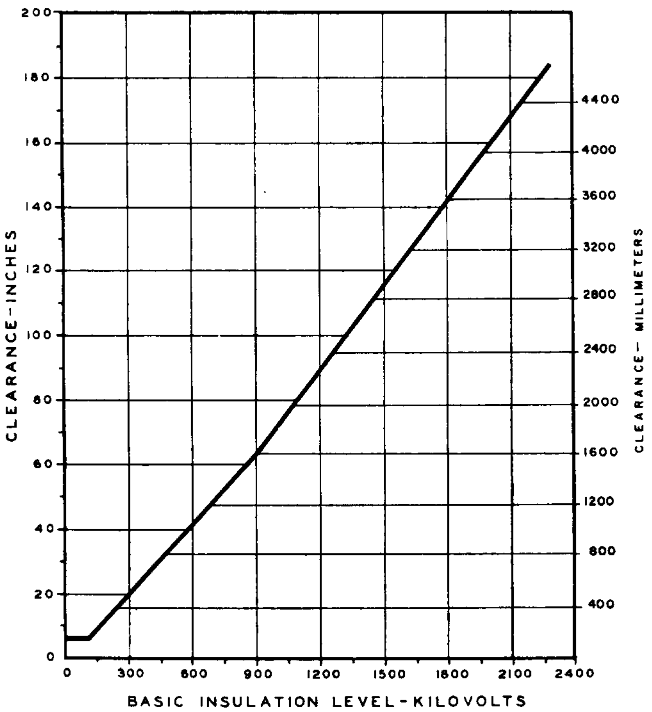


Figure 1-6.2 Clearance from Carbon Dioxide Equipment to Live Uninsulated Electrical Components.

1-7.1.2 The specifications shall state that the installation shall conform to this standard and meet the approval of the authority having jurisdiction.

1-7.1.3 The specifications shall include the specific tests that may be required to meet the approval of the authority having jurisdiction, and indicate how cost of testing is to be borne.

1-7.1.4 The specifications shall require the provision of equipment listed for the use intended.

1-7.2 **Plans and Approvals.** Plans and calculations shall be submitted for approval to the authority having jurisdiction before the work starts. Their preparation shall be entrusted to none but fully experienced and qualified persons.

1-7.2.1 These plans shall be drawn to an indicated scale or be suitably dimensioned and shall be made so that they can be easily reproduced.

1-7.2.2 These plans shall contain sufficient detail to enable the authority having jurisdiction to evaluate the hazard or hazards and to evaluate the effectiveness of the system. The details shall include the materials involved in the protected hazards, location of the hazards, the enclosure or limits and isolation of the hazards, and the area surrounding which might affect the protected hazards.

1-7.2.3 The detail on the system shall include information and calculations on the amount of CO_2; the location and flow rate of each nozzle including equivalent orifice area; the location, size and equivalent lengths of pipe, fittings and hose; and the location and size of the CO_2 storage facility. Information shall be submitted pertaining to the location and function of the detection devices, operating devices, auxiliary equipment, and electrical circuitry, if used. Sufficient information shall be indicated to identify properly the apparatus and devices used. Any special features shall be adequately explained.

1-7.2.4 When field conditions necessitate any material change from approved plans, the change shall be submitted to the authority having jurisdiction for approval.

1-7.2.5 When such material changes from approved plans are made, corrected "as-installed" plans shall be supplied to the owner and the authority having jurisdiction.

1-7.2.6 An instruction and maintenance manual which includes a full sequence of operation and a full set of system drawings and calculations shall be maintained in a protective enclosure.

1-7.3* **Approval of Installations.** The completed system shall be inspected and tested by qualified personnel to meet the approval of the authority having jurisdiction. Only listed or approved equipment and devices shall be used in the system. To determine that the system has been properly installed and will function as specified, the following shall be performed:

(a) A thorough visual inspection of the installed system and hazard area. The piping, operational equipment, and discharge nozzles shall be inspected for proper size and location. The locations of alarms and manual emergency releases shall be confirmed. The configuration of the hazard shall be compared to the original hazard specification. The hazard shall be inspected closely for unclosable openings and sources of agent loss which may have been overlooked in the original specification.

(b) A check of labeling of devices for proper designations and instructions. Nameplate data on the storage containers shall be compared to specifications.

(c) Nondestructive operational tests on all devices necessary for proper functioning of the system, including detection and actuation devices.

(d) A full discharge test shall be performed on all systems except when specifically waived by the authority having jurisdiction. When multiple hazards are protected from a common supply, then a full discharge test shall be performed for each hazard.

NOTE: Prior to testing, proper safety procedures shall be reviewed. See 1-6 and A-1-6.

1. Local Application — Full discharge of design quantity carbon dioxide through system piping to ensure carbon dioxide effectively covers the hazard for the full period of time required by the design specifications and all pressure operated devices function as intended.

2. Total Flooding — Full discharge of entire design quantity of carbon dioxide through system piping to ensure that carbon dioxide is discharged into the hazard, and that the concentration is achieved and maintained in the period of time required by the design specifications and all pressure operated devices function as intended.

3. Hand Held Hose Lines — Full discharge test of hand held hose line systems, requires evidence of liquid

flow from each nozzle with an adequate pattern of coverage.

1-8 Operation and Control of Systems.

1-8.1 Methods of Actuation. Systems shall be classified as automatic or manual in accordance with the following methods of actuation:

(a) *Automatic Operation.* Operation that does not require any human action.

(b) *Normal Manual Operation.* Operation of the system requiring human action where the device used to cause operation is located so as to be easily accessible at all times to the hazard. (*See 1-8.3.4.*) Operation of one control shall be all that is required to bring about the full operation of the system.

(c) *Emergency Manual Operation.* Operation of the system by human means where the device used to cause operation is fully mechanical in nature and is located at or near the device being controlled. Fully mechanical may incorporate the use of system pressure to complete operation of the device.

NOTE: THE EMERGENCY MANUAL CONTROL IS INTENDED FOR USE ONLY IN THE EVENT OF FAILURE OF AUTOMATIC OR NORMAL MANUAL ACTUATION. IF THERE IS NO TIME DELAY OR PREDISCHARGE ALARM WITH EMERGENCY MANUAL METHOD OF ACTUATION IT MUST BE ASCERTAINED THAT THE HAZARD AREA AND ADJOINING AREAS WHERE CARBON DIOXIDE MAY ACCUMULATE ARE CLEAR OF ALL PERSONNEL PRIOR TO OPERATION OF THIS DEVICE. THESE DEVICES SHALL BE CLEARLY MARKED TO INDICATE THIS WITH A WARNING PLACARD.

1-8.2 Detection of Fires. Fires or conditions likely to produce fire may be detected by visual (human senses) or by automatic means.

1-8.2.1 Reliance on visual detection shall be permitted only with permission of the authority having jurisdiction, where fires or conditions likely to produce fire can be readily detected by such means.

1-8.2.2* Automatic detection shall be by any listed or approved method or device that is capable of detecting and indicating heat, flame, smoke, combustible vapors, or an abnormal condition in the hazard such as process trouble that is likely to produce fire.

1-8.3 Operating Devices. Operating devices include carbon dioxide releasing devices or valves, discharge controls, and equipment shutdown devices, all of which are necessary for successful performance of the system.

1-8.3.1 Operation shall be by listed or approved mechanical, electrical, or pneumatic means.

1-8.3.2 All devices shall be designed for the service they will encounter and shall not be readily rendered inoperative or susceptible to accidental operation. Devices shall be normally designed to function properly from − 20 °F to 150 °F (− 29 °C to 66 °C) or marked to indicate temperature limitations.

1-8.3.3 All devices shall be located, installed, or suitably protected so that they are not subject to mechanical, chemical, or other damage which would render them inoperative.

1-8.3.4 The normal manual control for actuation shall be located so as to be conveniently and easily accessible at all times including the time of fire. This control shall cause the complete system to operate in its normal fashion. Operation of this device shall not cause the time delay to recycle. (*See 1-6.1.4.*)

1-8.3.5 All valves controlling the release and distribution of carbon dioxide shall be provided with an emergency manual control. This does not apply to slave high pressure cylinders. It is possible for the normal manual control to qualify as the emergency manual control if the provisions of 1-8.1 are satisfied.

The emergency means shall be easily accessible and located close to the valves controlled. If possible, the system should be designed so that emergency actuation can be accomplished from one location. This does not apply to slave high pressure cylinders.

Determination shall be made as to whether a time delay and predischarge alarm for emergency manual control are required based on the nature of the hazard and safety requirements.

1-8.3.6* Where gas pressure from pilot cylinders fed through the system discharge manifold (i.e., using back pressure rather than a separate pilot line) is used as a means for releasing remaining slave cylinders and the supply consists of less than three cylinders, one cylinder shall be used for such operation. If the supply consists of three cylinders or more, there shall be one pilot cylinder more than the minimum required to actuate the system. During the full discharge acceptance test, the extra pilot cylinder shall be arranged to operate as a slave cylinder.

1-8.3.7 Manual controls shall not require a pull of more than 40 lb (force) (178 N) nor a movement of more than 14 in. (356 mm) to secure operation.

1-8.3.8 Where the continuing operation of equipment associated with a hazard being protected could contribute to sustaining the fire in that hazard, the source of power or fuel shall be automatically shut off. All shutdown devices shall be considered integral parts of the system and shall function with the system operation.

1-8.3.9 All manual operating devices shall be identified as to the hazard they protect, the function they perform and the method of operation.

1-8.4 Supervision of automatic systems shall be provided unless specifically waived by the authority having jurisdiction. Interconnections between the components that are necessary for the control of the system and life safety, such as detection, actuation, alarms, power sources, etc., shall be supervised. An open circuit, ground fault condition, or loss of integrity in the pneumatic control lines that would impair full system operation shall result in a trouble signal. The alarm and trouble signals shall be transmitted by one of the following methods:

(a) Local alarm service which will cause an audio and visual signal at a constantly attended location (NFPA 72A),

(b) Proprietary alarm service (NFPA 72D),

(c) Remote alarm service (NFPA 72C), or

(d) Central station alarm service (NFPA 71).

Exception: High pressure pneumatic operated slave cylinder connections immediately adjacent to pilot cylinders need not be supervised.

1-8.5 Alarms and Indicators. Alarms or indicators, or both, are used to indicate the operation of the system, hazard to personnel, or failure of any supervised device or equipment. The device may be audible, visual, or olfactory. The type, number, and location of the devices shall be such that their purpose is satisfactorily accomplished. The extent and type of alarm or indicator equipment, or both, shall be approved.

1-8.5.1 An alarm or indicator shall be provided to show that the system has operated and needs recharging.

1-8.5.2* An alarm shall be provided to indicate the operation of automatic systems and that immediate personnel response is desired.

1-8.5.3 Predischarge alarms shall be provided to give positive warning of a discharge where hazard to personnel may exist, except as noted in 1-8.1(c) and 1-8.3.5. Such alarms shall function to warn against personnel entry into hazardous areas as long as such hazards exist or until such hazards are properly recognized. (*See Section 1-6.*)

1-8.5.4 Alarms indicating failure of supervised devices or equipment shall give prompt and positive indication of any failure and shall be distinctive from alarms indicating operation or hazardous conditions.

1-8.6* Power Sources. The primary source of energy for the operation and control of the system shall have the capacity for intended service and shall be reliable. When failure of the primary source of energy will jeopardize protection provided for the hazard, the life safety, or both, an independent secondary (standby) power supply shall supply energy to the system in the event of total failure or low voltage (less than 85 percent of the nameplate voltages) of the primary (main) power supply. The secondary (standby) supply shall be capable of operating the system under maximum normal load for 24 hours and then be capable of operating the system continuously for the full design discharge period. The secondary (standby) power supply shall automatically transfer to operate the system within 30 seconds of the loss of the primary (main) power supply.

1-9 Carbon Dioxide Supply.

1-9.1* Quantities. The amount of carbon dioxide in the system shall be at least sufficient for the largest single hazard protected or group of hazards which are to be protected simultaneously.

1-9.1.1 Where hand hose lines may be used on a hazard protected by a fixed system, separate supplies shall be provided unless sufficient carbon dioxide is provided to ensure that the fixed protection for the largest single hazard upon which the hose lines may be used will not be jeopardized. (*See 4-1.1.*)

1-9.1.2 Where continuous protection is required, the reserve quantity shall be as many multiples of these minimum amounts as the authority having jurisdiction considers necessary. (*See 1-9.3.*)

1-9.1.3 Both primary and reserve supplies for fixed storage systems shall be permanently connected to the piping and arranged for easy changeover, except where the authority having jurisdiction permits an unconnected reserve.

1-9.2* Quality. Carbon dioxide used for initial supply and replenishment shall be of good commercial grade, free of water and other contaminants that might cause container corrosion or interfere with free discharge through nozzle orifices. In general, carbon dioxide obtained by converting dry ice to liquid will not be satisfactory unless it is properly processed to remove excess water and oil.

1-9.2.1 The vapor phase shall be not less than 99.5 percent carbon dioxide with no detectable off-taste or odor.

1-9.2.2 The water content of the liquid phase shall be not more than 0.01 percent by weight [-30 °F (-34 °C) dew point].

1-9.2.3 Oil content shall be not more than 10 ppm by weight.

1-9.3 Replenishment. The time needed to obtain carbon dioxide for replenishment to restore systems to operating condition shall be considered as a major factor in determining the reserve supply needed.

1-9.4 Storage Containers. Storage containers and accessories shall be so located and arranged that inspection, testing, recharging, and other maintenance is facilitated and interruption to protection is held to a minimum.

1-9.4.1 Storage containers shall be located as near as possible to the hazard or hazards they protect, but they shall not be located where they will be exposed to a fire or explosion in these hazards.

1-9.4.2 Storage containers shall not be located so as to be subject to severe weather conditions or be subject to mechanical, chemical, or other damage.

1-9.4.3 When excessive climatic or mechanical exposures are expected, suitable guards or enclosures shall be provided.

1-9.5* High Pressure Storage Containers. The carbon dioxide supply shall be stored in rechargeable containers designed to hold pressurized carbon dioxide in liquid form at atmospheric temperatures corresponding to a nominal pressure of 850 psi (58.6 bars) at 70 °F (21 °C).

1-9.5.1 High pressure containers or cylinders shall be constructed, tested, and marked in accordance with U.S. Department of Transportation specifications[1] (in current

[1]Secs. 178.36 and 178.37 of Title 49, Transportation, *Code of Federal Regulations*. Parts 171-190 (DOT). Available from the Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20401.

effect upon date of manufacture and test) for DOT-3A, 3AA-1800, or higher, seamless steel cylinders. Charged cylinders shall be tested for tightness before shipment in accordance with an approved procedure.

1-9.5.2 High pressure cylinders used in fire extinguishing systems shall not be recharged without hydrostatic test (and remarking) if more than 5 years have elapsed from the date of last test. Cylinders continuously in service without discharging may be retained in service for a maximum of 12 years from the date of last hydrostatic test. At the end of 12 years, they shall be discharged and retested before being returned to service.

NOTE: Transporting charged carbon dioxide cylinders which have not been hydrostatically tested within 5 years may be illegal. Federal and local regulations should be consulted.

1-9.5.3 Each cylinder shall be provided with a safety device to relieve excess pressures safely in advance of the rated cylinder test pressure. DOT-approved, frangible safety discs shall be accordingly fitted.

1-9.5.4 When manifolded, cylinders shall be adequately mounted and suitably supported in a rack provided for the purpose, including facilities for convenient individual servicing or content weighings. Automatic means shall be provided to prevent the loss of carbon dioxide from the manifold if the system is operated when any cylinder is removed for maintenance.

1-9.5.5 Individual cylinders shall be used having a standard weight capacity of 5, 10, 15, 20, 25, 35, 50, 75 or 100 lb (2.3, 4.5, 6.8, 9.1, 11.4, 15.9, 22.7, 34.1 or 45.4 kg) of carbon dioxide contents except for special temperature charges (*see 1-9.5.6*). In a multiple cylinder system, all cylinders supplying the same manifold outlet for distribution of agent shall be interchangeable and of one select size.

1-9.5.6 The ambient storage temperatures for (a) local application systems, shall not exceed 120 °F (49 °C) nor be less than 32 °F (0 °C) and (b) total flooding systems, shall not exceed 130 °F (54 °C) nor be less than 0 °F (– 18 °C) unless the system is designed for proper operation with storage temperatures outside of this range. External heating or cooling may be used to keep the temperature within this range. When special cylinder charges are used, the cylinders shall be appropriately marked in a permanent manner.

1-9.6* Low Pressure Storage Containers. Low pressure storage containers shall be designed to maintain the carbon dioxide supply at a nominal pressure of 300 psi (20.7 bars) corresponding to a temperature of approximately 0 °F (– 18 °C).

1-9.6.1 The pressure container shall be made, tested, approved, equipped, and marked in accordance with the current specifications of the American Society of Mechanical Engineers (ASME) Code for Unfired Pressure Vessels[1] or in the case of mobile supply containers if applicable the requirements of the Department of Transportation (DOT)[1] or both. The design working pressure shall be at least 325 psi (22.4 bars).

1-9.6.2* In addition to the code requirements, each pressure container shall be equipped with a liquid level gauge, a pressure gauge, and a high-low pressure supervisory alarm set at approximately 315 and 250 psi (21.7 and 17.2 bars).

1-9.6.3 The pressure container shall be insulated and equipped with refrigeration or heating or both if necessary. Heating need not be provided unless known meteorological data indicate the occurrence of ambient temperatures which will cool the contents of the tank sufficiently to reduce the pressure below 250 psi (17.2 bars) [approximately – 10 °F (– 23 °C)].

1-9.6.4 The refrigeration system shall be capable of maintaining 0 °F (– 18 °C) in the pressure container under the highest expected ambient temperature. Operation shall be automatically controlled within practical limits.

1-9.6.5 The heating system, when required, shall be capable of maintaining 0 °F (– 18 °C) in the pressure container under the lowest expected ambient temperature. Operation shall be automatically controlled within practical limits.

1-10 Distribution Systems.

1-10.1 Pipe and Fittings. Piping shall be of noncombustible material having physical and chemical characteristics such that its deterioration under stress can be predicted with reliability. Special corrosion resistant materials or coatings may be required in severely corrosive atmospheres. Examples of materials for piping and the standards covering these materials are:

(a) Ferrous Piping: Black or galvanized steel pipe shall be either ASTM A-53 seamless or electric welded, Grade A or B, or ASTM A-106, Grade A, B, or C. ASTM A-120 and ordinary cast-iron pipe shall not be used.

1. In systems using high pressure supply, ¾-in. and smaller pipe may be Schedule 40. Pipe 1 in. through 4 in. shall be a minimum of Schedule 80. Furnace butt weld ASTM-53 pipe shall not be used.

2. In systems using low pressure supply, pipe shall be minimum of Schedule 40. Furnace butt weld ASTM-53 pipe may be used.

(b) This standard does not preclude the use of other piping materials such as stainless steel or other piping or tubing providing, for high pressure supply, an internal pressure of 3,000 psi, and for low pressure supply, an internal pressure of 450 psi, which will not cause material stress greater than the material's yield point when calculated according to ANSI B-31.1, *Power Piping Code.*

1-10.1.1* Flexible piping, tubing, or hoses (including connections), where used, shall be of approved materials

[1]*Code for Unfired Pressure Vessels for Petroleum Liquids and Gases* (ASME; API-ASME). Available from The American Society of Mechanical Engineers, 345 East 47th St., New York, NY 10017.

[1]*Title 49, Transportation, Code of Federal Regulations.* Parts 171-190 (DOT). Available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20401

and pressure ratings. It shall be inspected regularly in accordance with 1-11.2.7.

1-10.1.2 Fittings. Class 150 and cast-iron fittings shall not be used.

(a) *High Pressure Fittings.* Class 300 malleable or ductile iron fittings shall be used through 2-in. IPS and forged steel fittings in all larger sizes. Flanged joints upstream of any stop valves shall be Class 600 and downstream of any stop valves or in systems with no stop valves may be Class 300.

(b) *Low Pressure Fittings.* Class 300 malleable or ductile iron fittings shall be used through 3-in. IPS and 1000-lb ductile iron or forged steel fittings in all larger sizes. Flanged joints shall be Class 300.

1-10.1.3 Welded joints, screwed or flanged fittings (malleable iron or ductile iron) may be used. Mechanical grooved couplings and fittings may be used if they are specifically listed for carbon dioxide service. Flush bushings shall not be used. When hex bushings are used, more than one pipe size reduction or a 3000-lb (6615-kg) forged steel bushing shall be provided to maintain adequate strength. Suitable flared, compression-type, or brazed fittings shall be used with copper or brass tubing. Where brazed joints are used, the brazing alloy shall have a melting point of 1000 °F (538 °C) or higher.

1-10.1.4 In systems using high pressure supply, the piping system shall have a minimum bursting pressure of 5000 psi (413.7 bars).

1-10.1.5 In systems using low pressure supply, the piping system shall have a minimum bursting pressure of 1800 psi (124.1 bars).

1-10.2 Arrangement and Installation of Piping and Fittings. Piping shall be installed in accordance with good commercial practices and the equipment manufacturer's recommendations.

1-10.2.1* All piping shall be laid out to reduce friction losses to a reasonable minimum and care shall be taken to avoid possible restrictions due to foreign matter or faulty fabrication.

1-10.2.2 The piping system shall be securely supported with due allowance for agent thrust forces, thermal expansion and contraction, and shall not be subject to mechanical, chemical, or other damage. Where explosions are possible, the piping system shall be hung from supports that are least likely to be displaced.

1-10.2.3 Pipe shall be reamed and cleaned before assembly, and after assembly the entire piping system shall be blown out before nozzles or discharge devices are installed.

1-10.2.4 In systems where valve arrangement introduces sections of closed piping, such sections shall be equipped with pressure relief devices or the valves shall be designed to prevent entrapment of liquid carbon dioxide. The pressure relief devices shall operate at between 2400 and 3000 psi (165.5 and 206.9 bars) on systems supplied with high pressure storage, and at 450 psi (31.0 bars) on systems supplied by low pressure storage. Where pressure operated cylinder valves are used, a means shall be provided to vent any cylinder gas leakage from the manifold, but which will prevent loss of gas when the system operates.

1-10.2.5 All pressure relief devices shall be of such design and so located that the discharge of CO_2 therefrom will not injure personnel or be otherwise objectionable.

1-10.3 Valves. All valves shall be suitable for the intended use, particularly in regard to flow capacity and operation. They shall be used only under temperatures and other conditions for which they are listed or approved.

1-10.3.1 Valves used in systems with high pressure storage and constantly under pressure shall have a minimum bursting pressure of 6000 psi (413.7 bars) while those not under constant pressure shall have a minimum bursting pressure of at least 5000 psi (344.8 bars).

1-10.3.2 Valves used in systems using low pressure storage shall withstand a hydrostatic test to 1800 psi (124.1 bars) without permanent distortion.

1-10.3.3 Valves shall be located, installed or suitably protected so that they are not subject to mechanical, chemical, or other damage which would render them inoperative.

1-10.3.4 Valves shall be rated for equivalent length in terms of the pipe or tubing sizes with which they will be used. The equivalent length of cylinder valves shall include siphon tube, valve, discharge head and flexible connector.

1-10.4 Discharge Nozzles. Discharge nozzles shall be suitable for the use intended and shall be listed or approved for discharge characteristics. The discharge nozzle consists of the orifice and any associated horn, shield, or baffle.

1-10.4.1 Discharge nozzles shall be of adequate strength for use with the expected working pressures, be able to resist nominal mechanical abuse, and constructed to withstand expected temperatures without deformation.

1-10.4.2 Discharge orifices shall be of corrosion resistant metal.

1-10.4.3 Discharge nozzles used in local application systems shall be so connected and supported that they may not readily be put out of adjustment.

1-10.4.4* Discharge nozzles shall be permanently marked to identify the nozzle and to show the equivalent single orifice diameter regardless of shape and number of orifices. This equivalent diameter shall refer to the orifice diameter of the "Standard" single orifice type nozzle having the same flow rate as the nozzle in question. The marking shall be readily discernible after installation. The "Standard" orifice is an orifice having a rounded entry with a coefficient of discharge not less than 0.98 and flow characteristics as given in Tables 1-10.4.4(b) and 1-10.4.4(c).

For examples of equivalent orifice diameters see Table 1-10.4.4(a). The orifice code numbers indicate the equivalent single orifice diameter in 1/32 in. (0.8 mm) increments. Orifice sizes other than those shown in Table 1-10-4.4(a) may be used and may be marked as decimal orifice equipment.

Table 1-10.4.4(a)
Equivalent Orifice Sizes

Orifice Code No.	Equivalent Single Orifice Diameter inches	mm	Equivalent Single Orifice Area inches²	mm²
1	1/32	0.79	.0008	0.49
1.5	3/64	1.19	.0017	1.11
2	1/16	1.59	.0031	1.98
2.5	5/64	1.98	.0047	3.09
3	3/32	2.38	.0069	4.45
3.5	7/64	2.78	.0094	6.06
4	1/8	3.18	.0123	7.94
4.5	9/64	3.57	.0155	10.00
5	5/32	3.97	.0192	12.39
5.5	11/64	4.37	.0232	14.97
6	3/16	4.76	.0276	17.81
6.5	13/64	5.16	.0324	20.90
7	7/32	5.56	.0376	24.26
7.5	15/64	5.95	.0431	27.81
8	1/4	6.35	.0491	31.68
8.5	17/64	6.75	.0554	35.74
9	9/32	7.14	.0621	40.06
9.5	19/64	7.54	.0692	44.65
10	5/16	7.94	.0767	49.48
11	11/32	8.73	.0928	59.87
12	3/8	9.53	.1105	71.29
13	13/32	10.32	.1296	83.61
14	7/16	11.11	.1503	96.97
15	15/32	11.91	.1725	111.29
16	1/2	12.70	.1964	126.71
18	9/16	14.29	.2485	160.32
20	5/8	15.88	.3068	197.94
22	11/16	17.46	.3712	239.48
24	3/4	19.05	.4418	285.03
32	1	25.40	.785	506.45
48	1 ½	38.40	1.765	1138.71
64	2	50.80	3.14	2025.80

Table 1-10.4.4(b) Discharge Rate Per Square Inch of Equivalent Orifice Area for Low Pressure Storage [300 psia (20.7 bars)]

Orifice Pressure psia	bars	Discharge Rate lbs/min/in.²	kg/min/mm²
300	20.7	4220	2.970
290	20.0	2900	2.041
280	19.3	2375	1.671
270	18.6	2050	1.443
260	17.9	1825	1.284
250	17.2	1655	1.165
240	16.5	1525	1.073
230	15.9	1410	0.992
220	15.2	1305	0.918
210	14.5	1210	0.851
200	13.8	1125	0.792
190	13.1	1048	0.737
180	12.4	977	0.688
170	11.7	912	0.642
160	11.0	852	0.600
150	10.3	795	0.559

1-10.4.5 Discharge nozzles shall be provided with frangible discs or blow-out caps where clogging by foreign materials is likely. These devices shall provide an unobstructed opening upon system operation.

1-10.5* Pipe and Orifice Size Determination. Pipe sizes and orifice areas shall be selected on the basis of calculations to deliver the required rate of flow at each nozzle.

Table 1-10.4.4(c) Discharge Rate Per Square Inch of Equivalent Orifice Area for High Pressure Storage [750 psia (51.7 bars)]

Orifice Pressure psia	bars	Discharge Rate lbs/min/in.²	kg/min/mm²
750	51.7	4630	3.258
725	50.0	3845	2.706
700	48.3	3415	2.403
675	46.5	3090	2.174
650	44.8	2835	1.995
625	43.1	2615	1.840
600	41.4	2425	1.706
575	39.6	2260	1.590
550	37.9	2115	1.488
525	36.2	1985	1.397
500	34.5	1860	1.309
475	32.8	1740	1.224
450	31.0	1620	1.140
425	29.3	1510	1.063
400	27.6	1400	0.985
375	25.9	1290	0.908
350	24.1	1180	0.830
325	22.4	1080	0.760
300	20.7	980	0.690

1-10.5.1 The following equation or curves developed therefrom shall be used to determine the pressure drop in the pipe line:

$$Q^2 = \frac{(3647)\,(D^{5.25}Y)}{L + 8.08\,(D^{1.25}Z)}$$

Where Q = Flow rate in lbs/ min
D = Inside pipe diameter (actual) in inches
L = Equivalent length of pipeline in feet
Y & Z = Factors depending on storage and line pressure

For SI Units

$$Q_M{}^2 = \frac{10^{-5} \times 0.8725\ D^{5.25}\ Y}{L + 0.04319\ D^{1.25}\ Z}$$

Where
Q_M = Flow rate in kg/min
D = Inside pipe diameter (actual) in mm
L = Equivalent length of pipeline in m
Y and Z = Factors depending on storage and line pressure

NOTE: For further explanation see Appendix A-1-10.5.

1-10.5.2 For systems with low pressure storage, flow shall be calculated on the basis of an average storage pressure of 300 psia (20.7 bars) during discharge. The discharge rate for equivalent orifices shall be based on the values given in Table 1-10.4.4(b). Design nozzle pressures shall not be less than 150 psia (10.3 bars).

1-10.5.3 For systems with high pressure storage, flow shall be calculated on the basis of an average storage pressure of 750 psia (51.7 bars) during discharge for normal 70 °F (21 °C) storage. The discharge rate through equivalent orifices shall be based on the values given in Table 1-10.4.4(c). Design nozzle pressure at 70 °F (21 °C) storage shall be not less than 300 psia (20.7 bars).

1-11 Inspection, Maintenance, and Instruction.

1-11.1* A manufacturer's test and maintenance procedure shall be provided to the owner for testing and maintenance of the system. This procedure shall provide for the initial testing of the equipment as well as for periodic test inspection and maintenance of the system.

1-11.2* Inspection and Tests. At least annually, all carbon dioxide systems shall be thoroughly inspected and tested for proper operation by competent personnel. (*See 1-11.4.*)

1-11.2.1 The goal of this inspection and testing shall be not only to ensure that the system is in full operating condition, but shall indicate the probable continuance of that condition until the next inspection.

1-11.2.2 Suitable discharge tests shall be made when any inspection indicates their advisability.

Prior to testing, proper safety procedures shall be reviewed. (*See 1-6 and A-1-6.*)

1-11.2.3 An inspection report with recommendations shall be filed with the owner.

1-11.2.4 Between the regular service contract inspection or tests, the system shall be inspected visually or otherwise by approved or competent personnel, following an approved schedule.

1-11.2.5 At least semiannually, all high pressure cylinders shall be weighed and the date of the last hydrostatic test noted (*see 1-9.5.2*). If, at any time, a container shows a loss in net content of more than 10 percent, it shall be refilled or replaced.

1-11.2.6 At least weekly the liquid level gauges of low pressure containers shall be observed. If at any time a container shows a loss of more than 10 percent, it shall be refilled, unless the minimum gas requirements are still provided.

1-11.2.7 All system hoses including those used as flexible connectors shall be examined annually for damage. If visual examination shows any deficiency, the hose shall be replaced or tested as follows:

1-11.2.7.1 All system hoses including those used as flexible connectors shall be tested at 2500 psi for high pressure systems, and at 900 psi for low pressure systems.

(a) Remove the hose from any attachment.

(b) Hoses for hand lines shall be checked for electrical continuity between couplings.

(c) The hose assembly is then to be placed in a protective enclosure designed to permit visual observation of the test.

(d) The hose must be completely filled with water before testing.

(e) Pressure then is applied at a rate-of-pressure rise to reach the test pressure within a minimum of one minute. The test pressure is to be maintained for one full minute. Observations are then made to note any distortion or leakage.

(f) If the test pressure has not dropped and if the couplings have not moved, the pressure is released. The hose assembly is then considered to have passed the hydrostatic test if no permanent distortion has taken place.

(g) Hose assembly passing the test must be completely dried internally. If heat is used for drying, the temperature must not exceed 150 ° (66 °C).

(h) Hose assemblies failing the above tests must be marked and destroyed. They shall be replaced with new assemblies.

(i) Hose assemblies passing the test shall be suitably marked with the date of the test on the hose.

1-11.2.7.2 Testing. All system hoses including those used as flexible connectors shall be tested every five years in accordance with 1-11.2.7.1.

1-11.3 Maintenance. These systems shall be maintained in full operating condition at all times. Use, impairment, and restoration of this protection shall be reported promptly to the authority having jurisdiction.

1-11.3.1 Any troubles or impairments shall be corrected at once by competent personnel.

1-11.4 Instruction. All persons who may be expected to inspect, test, maintain, or operate carbon dioxide fire extinguishing systems shall be thoroughly trained and kept thoroughly trained in the functions they are expected to perform.

Chapter 2 Total Flooding Systems

2-1* General Information.

2-1.1 Description. A total flooding system consists of a fixed supply of carbon dioxide permanently connected to fixed piping, with fixed nozzles arranged to discharge carbon dioxide into an enclosed space or enclosure about the hazard.

2-1.2 Uses. This type of system may be used where there is a permanent enclosure about the hazard that is adequate to enable the required concentration to be built up, and to be maintained for the required period of time to ensure the complete and permanent extinguishment of the fire in the specific combustible material or materials involved.

2-1.2.1 Examples of hazards that may be successfully protected by total flooding systems include rooms, vaults, enclosed machines, ducts, ovens, containers, and the contents thereof.

2-1.3 General Requirements. Total flooding systems shall be designed, installed, tested, and maintained in accordance with the applicable requirements in the previous chapter and with the additional requirements set forth in this chapter.

2-1.4 Safety Requirements. Reference is made to 1-6, A-1-6, and 1-8.5 regarding hazards to personnel due to obscuration of vision and reduction of oxygen concentration below that which will support life not only in the immediate area of discharge, but in adjacent areas to which gas may migrate.

2-2 Hazard Specifications.

2-2.1 Enclosure. Under this class of protection, a reasonably well-enclosed space is assumed in order to minimize the loss of the extinguishing medium. The area of allowable unclosable openings depends upon the type of combustibles involved.

2-2.1.1 For flash or surface type fires, such as will be present with flammable liquids, any unclosable openings shall be compensated for by additional carbon dioxide as specified in 2-3.5.1. If the quantity of carbon dioxide required for compensation exceeds the basic quantities required for flooding without leakage, the system may be designed for local application in accordance with Chapter 3.

2-2.1.2 For deep-seated fires, such as will be involved with solids, unclosable openings shall be restricted to those bordering or actually in the ceiling, if the size of the openings exceeds the pressure relief venting requirements set forth in 2-6.2.1.

2-2.1.3 To prevent fire from spreading through openings to adjacent hazards or work areas which may be possible reignition sources, such openings shall be provided with automatic closures or local application nozzles. The gas required for such protection shall be in addition to the normal requirement for total flooding (*see 3-4.3.6*). When neither method is practical, protection shall be extended to include these adjacent hazards or work areas (*see 3-4.3.6*).

2-2.1.4 In the case of process and storage tanks where safe venting of flammable vapors and gases cannot be realized, the use of external local application systems outlined in 3-4.3.6 is required.

2-2.2 Leakage and Ventilation. Since the efficiency of carbon dioxide systems depends upon the maintenance of an extinguishing concentration of carbon dioxide, leakage of gas from the space shall be kept to a minimum and compensated for by applying extra gas.

2-2.2.1 Where possible, openings such as doorways, windows, etc., shall be arranged to close automatically before or simultaneously with the start of the carbon dioxide discharge, or 2-3.5.1 and 2-4.4.1 shall be followed. For personnel safety, see 1-6.2.

2-2.2.2 Where forced air ventilating systems are involved, they shall be preferably shut down or closed, or both, before or simultaneously with the start of the carbon dioxide discharge, or additional compensating gas shall be provided (*see 2-3.5.2*).

2-2.3* Types of Fires. Fires which can be extinguished by total flooding methods may be divided into two categories: namely, (a) surface fires involving flammable liquids, gases and solids, and (b) deep-seated fires involving solids subject to smoldering.

2-2.3.1 Surface fires are the most common hazard particularly adaptable to extinguishment by total flooding systems. They are subject to prompt extinguishment when carbon dioxide is quickly introduced into the enclosure in sufficient quantity to overcome leakage and provide an extinguishing concentration for the particular materials involved.

2-2.3.2 For deep-seated fires, the required extinguishing concentration shall be maintained for a sufficient period of time to allow the smoldering to be extinguished and the material to cool to a point at which reignition will not occur when the inert atmosphere is dissipated. In any event, it is necessary to inspect the hazard immediately thereafter to make certain that extinguishment is complete and to remove any material involved in the fire.

2-3* Carbon Dioxide Requirements for Surface Fires.

2-3.1 General. The quantity of carbon dioxide for surface type fires is based on average conditions assuming fairly prompt extinguishment. A reasonable allowance for normal leakage is included in the basic volume factors, but corrections shall be made for the type material involved and any other special conditions.

2-3.2 Flammable Materials. Proper consideration shall be given to the determination of the design concentration of carbon dioxide required for the type of flammable material involved in the hazard. The design concentration is determined by adding a suitable factor (20 percent) to the minimum effective concentration. In no case shall a concentration less than 34 percent be used.

2-3.2.1 Table 2-3.2.1 gives the theoretical minimum carbon dioxide concentration and the suggested minimum design carbon dioxide concentration to prevent ignition of some common liquids and gases.

2-3.2.2 For materials not given in Table 2-3.2.1, the minimum theoretical carbon dioxide concentration shall be obtained from some recognized source or determined by test. If maximum residual oxygen values are available, the theoretical carbon dioxide concentration may be calculated by the following formula:

$$\%CO_2 = \frac{(21 - O_2)}{21} \times 100$$

2-3.3 Volume Factor. The volume factor used to determine the basic quantity of carbon dioxide to protect an enclosure containing a material requiring a design concentration of 34 percent shall be in accordance with Table 2-3.3.

2-3.3.1 In figuring the net cubic capacity to be protected, due allowance may be made for permanent nonremovable impermeable structures materially reducing the volume.

2-3.3.2 As the average small space has proportionately more boundary area per enclosed volume than a larger space, greater proportionate leakages are anticipated and accounted for by the graded volume factors in Table 2-3.3.

2-3.3.3 The least gas quantities for the smallest volumes are tabulated in order to clarify the intent of Column B and thus avoid possible overlapping at borderline volumes.

2-3.3.4 In two or more interconnected volumes where "free flow" of carbon dioxide can take place, the carbon dioxide quantity shall be the sum of the quantities calculated for each volume, using its respective volume factor from Table 2-3.3 or 2-3.3(M). If one volume requires greater than normal concentration (*see 2-3.4*), the higher concentration shall be used in all interconnected volumes.

Table 2-3.2.1
Minimum Carbon Dioxide Concentrations for Extinguishment

Material	Theoretical Min. CO_2 Concentration (%)	Minimum Design CO_2 Concentration (%)
Acetylene	55	66
Acetone	27*	34
Aviation Gas Grades 115/145	30	36
Benzol, Benzene	31	37
Butadiene	34	41
Butane	28	34
Butane - I	31	37
Carbon Disulfide	60	72
Carbon Monoxide	53	64
Coal or Natural Gas	31*	37
Cyclopropane	31	37
Diethyl Ether	33	40
Dimethyl Ether	33	40
Dowtherm	38*	46
Ethane	33	40
Ethyl Alcohol	36	43
Ethyl Ether	38*	46
Ethylene	41	49
Ethylene Dichloride	21	34
Ethylene Oxide	44	53
Gasoline	28	34
Hexane	29	35
Higher Paraffin Hydrocarbons $C_n H_{2m}$ + 2m - 5	28	34
Hydrogen	62	75
Hydrogen Sulfide	30	36
Isobutane	30*	36
Isobutylene	26	34
Isobutyl Formate	26	34
JP-4	30	36
Kerosene	28	34
Methane	25	34
Methyl Acetate	29	35
Methyl Alcohol	33	40
Methyl Butene - I	30	36
Methyl Ethyl Ketone	33	40
Methyl Formate	32	39
Pentane	29	35
Propane	30	36
Propylene	30	36
Quench, Lube Oils	28	34

NOTE: The theoretical minimum extinguishing concentrations in air for the above materials were obtained from a compilation of Bureau of Mines Limits of Flammability of Gases and Vapors (Bulletins 503 and 627). Those marked with * were calculated from accepted residual oxygen values.

2-3.4 Material Conversion Factor. For materials requiring a design concentration over 34 percent, the basic quantity of carbon dioxide calculated from the volume factor given in Table 2-3.3 shall be increased by multiplying this quantity by the appropriate conversion factor given in Figure 2-3.4.

Table 2-3.3 Flooding Factors

(A) Volume of Space (cu ft Incl.)	(B) Volume Factor (ft^3/lb CO_2)	(lb CO_2/ft^3)	(C) Calculated Quan. (lb) Not Less Than
Up to 140	14	.072	—
141– 500	15	.067	10
501– 1600	16	.063	35
1601– 4500	18	.056	100
4501–50,000	20	.050	250
Over 50,000	22	.046	2500

Table 2-3.3(M) Flooding Factors

(A) Volume of Space (m^3 Incl.)	(B) Volume Factor (m^3/kg CO_2)	(kg CO_2/m^3)	(C) Calculated Quan. (kg) Not Less Than
Up to 3.96	0.86	1.15	—
3.97– 14.15	0.93	1.07	4.5
14.16– 45.28	0.99	1.01	15.1
45.29–127.35	1.11	0.90	45.4
127.36–1415.0	1.25	0.80	113.5
Over 1415.0	1.38	0.77	1135.0

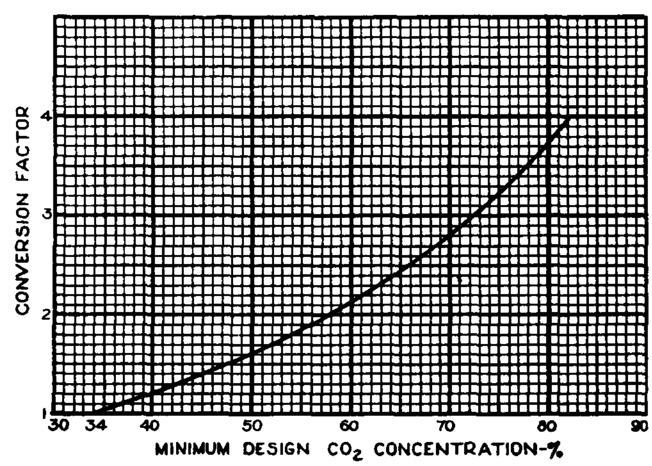


Figure 2-3.4 Material Conversion Factors.

2-3.5 Special Conditions. Additional quantities of carbon dioxide shall be provided to compensate for any special condition that may adversely affect the extinguishing efficiency.

2-3.5.1* Any openings that cannot be closed at the time of extinguishment shall be compensated for by the addition of a quantity of carbon dioxide equal to the anticipated loss at the design concentration during a 1-minute period. This amount of carbon dioxide shall be applied through the regular distribution system. (*See 2-2.1.1 and A-2-5.3.3.*)

2-3.5.2 For ventilating systems which cannot be shut down, additional carbon dioxide shall be added to the space through the regular distribution system in an amount computed by dividing the volume moved during the liquid discharge period by the flooding factor. This shall be multiplied by the material conversion factor (determined in Figure 2-3.4) when the design concentration is greater than 34 percent.

2-3.5.3* For applications where the normal temperature of the enclosure is above 200 °F (93 °C), a 1-percent increase in the calculated total quantity of carbon dioxide shall be provided for each additional 5 °F (− 15 °C) above 200 °F (93 °C).

2-3.5.4 For applications where the normal temperature of the enclosure is below 0 °F (− 18 °C), a 1-percent increase in the calculated total quantity of carbon dioxide shall be provided for each degree below 0 °F (− 18 °C).

2-3.5.5 Under normal conditions, surface fires are usually extinguished during the discharge period. Except for unusual conditions, it will not be necessary to provide extra carbon dioxide to maintain the concentration.

2-3.5.6 A flooding factor of 8 ft³/lb shall be used in ducts and covered trenches. If the combustibles represent a deep-seated fire, it shall be treated as described in Section 2-4.

2-4 Carbon Dioxide Requirements for Deep-seated Fires.

2-4.1* General. The quantity of carbon dioxide for deep-seated type fires is based on fairly tight enclosures. After the design concentration is reached, the concentration shall be maintained for a substantial period of time, but not less than 20 minutes. Any possible leakage shall be given special consideration since no allowance is included in the basic flooding factors.

2-4.2 Combustible Materials. For combustible materials capable of producing deep-seated fires, the required carbon dioxide concentrations cannot be determined with the same accuracy possible with surface burning materials. The extinguishing concentration will vary with the mass of material present because of the thermal insulating effects. Flooding factors have therefore been determined on the basis of practical test conditions.

2-4.2.1 The design concentrations listed in Table 2-4.2.1 shall be achieved for the hazards listed. Generally, the flooding factors have been found to provide proper design concentrations for the rooms and enclosures listed.

2-4.2.2 Flooding factors for other deep-seated fires shall be justified to the satisfaction of the authority having jurisdiction before use. Proper consideration shall be given to the mass of material to be protected because the rate of cooling is reduced by the thermal insulating effects.

Table 2-4.2.1 Flooding Factors for Specific Hazards

Design Concentration	Flooding Factor (ft³/lb CO_2)	(m³/kg CO_2)	(lb CO_2/ft³)	(kg CO_2/m³)	Specific Hazard
50	10	0.62	.100	1.60	Dry electrical hazards in general. (Spaces 0-2000 ft³)
50	12	0.75	.083 (200 lb) minimum	1.33 (91 kg) minimum	(Spaces greater than 2000 ft³)
65	8	0.50	.125	2.00	Record (bulk paper) storage, ducts, and covered trenches.
75	6	0.38	.166	2.66	Fur storage vaults, dust collectors.

NOTE: For further information, see A-2.1.

2-4.3 Volume Consideration. The volume of the space shall be determined in accordance with 2-3.3.1. The basic quantity of carbon dioxide required to protect an enclosure shall be obtained by treating the volume of the enclosure by the appropriate flooding factor given in 2-4.2.

2-4.4 Special Conditions. Additional quantities of carbon dioxide shall be provided to compensate for any special condition that may adversely affect the extinguishing efficiency. (*See 2-3.5.2, 2-3.5.3, and 2-3.5.4.*)

2-4.4.1 Any openings that cannot be closed at the time of extinguishment shall be compensated for by the addition of carbon dioxide equal in volume to the expected leakage volume during the extinguishing period. If leakage is appreciable, consideration shall be given to an extended discharge system as covered in 2-5.3. (*Also see 2-2.1.2.*)

2-5 Distribution System.

2-5.1 General. The distribution system for applying carbon dioxide to enclosed hazards shall be designed with due consideration for the materials involved and the nature of the enclosure, since these items may require various discharge times and rates of application.

2-5.2* Rate of Application. The minimum design rate of application shall be based on the quantity of carbon dioxide and the maximum time to achieve design concentration.

2-5.2.1 For surface fires the design concentration shall be achieved within 1 minute.

2-5.2.2 For high pressure systems, if a part of the hazard is to be protected by total flooding, the discharge rate for the total flooding portion shall be computed as specified in 3-3.2.3.

2-5.2.3 For deep-seated fires the design concentration shall be achieved within 7 minutes, but the rate shall be not less than that required to develop a concentration of 30 percent in 2 minutes.

2-5.3 Extended Rate of Application. Where leakage is appreciable and the design concentration must be obtained quickly and maintained for an extended period of time, carbon dioxide provided for leakage compensation may be applied at a reduced rate.

2-5.3.1 This type of system is particularly applicable to enclosed rotating electrical apparatus, such as generators, motors, and convertors, but it may also be used on ordinary total flooding applications where suitable.

2-5.3.2 The minimum design concentration shall be obtained within the time limits specified in 2-5.2.

2-5.3.3* The extended rate of discharge shall be sufficient to maintain the minimum concentration.

2-5.3.4* For enclosed rotating electrical equipment, a minimum concentration of 30 percent shall be maintained for the deceleration period, but not less than 20 minutes.

2-5.4 Piping Systems. Piping shall be designed in accordance with 1-10.5 to deliver the required rate of application at each nozzle.

2-5.4.1* High pressure storage temperatures may range from 0 °F (−18 °C) to 130 °F (54 °C) without requiring special methods of compensating for changing flow rates. (*See 1-9.5.6.*)

2-5.5 Nozzle Sizing and Distribution. Nozzles used in connection with total flooding systems with either high or low pressure supply shall be of a type suitable for the intended purpose, and shall be located to achieve the best results.

2-5.5.1 The types of nozzles selected and their placement shall be such that the discharge will not unduly splash flammable liquids or create dust clouds that might extend the fire, create an explosion, or otherwise adversely affect the contents of the enclosure. Nozzles vary in design and discharge characteristics and shall be selected on the basis of their adequacy for the use intended.

2-5.5.2 Spacing and sizing of nozzles in ductwork is dependent on many factors, i.e., velocity in duct, location and effectiveness of dampers, possible loading of duct walls with combustible deposits, duct length, and cross-sectional dimensions. The nozzle locations and sizing shall be selected to assure distribution of the carbon dioxide throughout the entire length of the ductwork. Automatic dampers shall be provided to close on system operation. No allowance is needed for inlet and outlet duct openings having surface hazards only (*see Table 2-4.2.1 and 2-3.5.6*).

2-6 Venting Consideration.

2-6.1 General. The venting of flammable vapors and pressure buildup from the discharge of quantities of carbon dioxide into closed spaces shall be considered. Venting of flammable vapors is covered in 2-2.1.4. The pressure venting consideration involves such variables as enclosure strength and injection rate.

2-6.2 Pressure Relief Venting. Porosity and leakages such as at doors, windows, and dampers, though not readily apparent or easily calculated, have been found to provide sufficient relief for the normal carbon dioxide flooding systems without need for additional venting. Record storage rooms, refrigerated spaces, and ductwork have also been found to need no additional venting when tested under their average system conditions.

2-6.2.1 For very tight enclosures, the area necessary for free venting shall be calculated from the following formula. Assuming the expansion of carbon dioxide to be 9 ft³/lb (0.56m³/kg) will give satisfactory results.

$$X = \frac{Q}{1.3\sqrt{P}}$$

where: X = Free venting area in in.²
Q = Calculated carbon dioxide flow rate in lbs/min.
P = Allowable strength of enclosure in lbs/ft²

For SI Units

$$X_M = \frac{23.9\,Q_M}{\sqrt{P_M}}$$

X_M = Free venting area mm²
Q_M = Calculated carbon dioxide flow rate in kg/min.
P_M = Allowable strength of enclosure, bars gage.

2-6.2.2 In many instances, particularly when hazardous materials are involved, relief openings are already provided for explosion venting. These and other available openings often provide adequate venting.

2-6.2.3 General construction practices provide the guide in Table 2-6.2.3 for considering the normal strength and allowable pressures of average enclosures.

Table 2-6.2.3 Strength and Allowable Pressures for Average Enclosures

Type Construction	Windage	Pressure	In. Water	PSI	Bars-Gage
Light Building	100 MPH	25 lb/ft² [1]	5	.175	0.012
Normal Building	140 MPH	50 lb/ft² [2]	10	.35	0.024
Vault Building	200 MPH	100 lb/ft²	20	.70	0.048

[1] Venting sash remains closed.
[2] Venting sash designed to open freely.

Chapter 3 Local Application Systems

3-1* General Information.

3-1.1 Description. A local application system consists of a fixed supply of carbon dioxide permanently connected to a system of fixed piping with nozzles arranged to discharge directly into the fire.

3-1.2 Uses. Local application systems may be used for the extinguishment of surface fires in flammable liquids, gases, and shallow solids where the hazard is not enclosed or where the enclosure does not conform to the requirements for total flooding.

3-1.2.1 Examples of hazards that may be successfully protected by local application systems include dip tanks, quench tanks, spray booths, oil-filled electric transformers, vapor vents, etc.

3-1.3 General Requirements. Local application systems shall be designed, installed, tested, and maintained in accordance with the applicable requirements in prévious chapters and with the additional requirements set forth in this chapter.

3-1.4 Safety Requirements. Reference is made to 1-6, 1-8.5, and A-1-6 regarding hazards to personnel due to obscuration of vision and reduction of oxygen concentration below that which will support life, not only in the immediate area of discharge but in adjacent areas to which gas may migrate.

3-2 Hazard Specifications.

3-2.1 Extent of Hazard. The hazard shall be so isolated from other hazards or combustibles that fire will not spread outside the protected area. The entire hazard shall be protected. The hazard shall include all areas that are, or may become, coated by combustible liquids or shallow solid coatings; such as areas subject to spillage, leakage, dripping, splashing, or condensation, and all associated materials or equipment; such as freshly coated stock, drain boards, hoods, ducts, etc., that might extend fire outside or lead fire into the protected area.

3-2.1.1 A series of interexposed hazards may be subdivided into smaller groups or sections with the approval of the authority having jurisdiction. Systems for such hazards shall be designed to give immediate independent protection to adjacent groups or sections as needed.

3-2.2 Location of Hazard. The hazard may be indoors, partly sheltered or completely out of doors. It is essential that the carbon dioxide discharge shall be such that winds or strong air currents do not impair the protection.

3-3 Carbon Dioxide Requirements.

3-3.1* General. The quantity of carbon dioxide required for local application systems shall be based on the total rate of discharge needed to blanket the area or volume protected and the time that the discharge must be maintained to assure complete extinguishment.

3-3.1.1* For systems with high pressure storage, the computed quantity of carbon dioxide shall be increased by 40 percent to determine nominal cylinder storage capacity since only the liquid portion of the discharge is effective. This increase in cylinder storage capacity is not required for the total flooding portion of combined local application-total flooding systems.

3-3.1.2* The quantity of carbon dioxide in storage shall be increased by an amount sufficient to compensate for liquid vaporized in cooling the piping.

3-3.2 Rate of Discharge. Nozzle discharge rates shall be determined by either the surface method or the volume method as covered in Sections 3-4 and 3-5.

3-3.2.1 The total rate of discharge for the system shall be the sum of the individual rates of all the nozzles or discharge devices used on the system.

3-3.2.2 For low pressure systems, if a part of the hazard is to be protected by total flooding, the discharge rate for the total flooding part shall be sufficient to develop the required concentration in not more than the discharge time used for the local application part of the system.

3-3.2.3 For high pressure systems, if a part of the hazard is to be protected by total flooding, the discharge rate for the total flooding part shall be computed by dividing the quantity required for total flooding by the factor 1.4 and by the time of the local application discharge in minutes.

$$Q_F = \frac{W_F}{1.4\ T_L}$$

Where: Q_F = Rate of flow for the total flooding portion in lbs/min (kg/min)
W_F = Total quantity of carbon dioxide for the total flooding portion in pounds (kg)
T_L = Liquid discharge time for the local application portion in minutes

3-3.3* Duration of Discharge. The minimum effective discharge time for computing quantity shall be 30 seconds. The minimum time shall be increased to compensate for any hazard condition that would require a longer cooling period to assure complete extinguishment.

3-3.3.1 Where there is a possibility that metal or other material may become heated above the ignition temperature of the fuel, the effective discharge time shall be increased to allow adequate cooling time.

3-3.3.2* Where the fuel has an autoignition point below its boiling point, such as paraffin wax and cooking oils, the effective discharge time shall be increased to permit cooling of the fuel to prevent reignition. The minimum discharge time shall be 3 minutes.

3-4 Rate by Area Method.

3-4.1 General. The area method of system design is used where the fire hazard consists primarily of flat surfaces or low-level objects associated with horizontal surfaces.

3-4.1.1 System design shall be based on listing or approval data for individual nozzles. Extrapolation of such data above or below the upper or lower limits shall not be permitted.

3-4.2 Nozzle Discharge Rates. The design discharge rate through individual nozzles shall be determined on the basis of location or projection distance in accordance with specific approvals or listings.

3-4.2.1* The discharge rate for overhead type nozzles shall be determined solely on the basis of distance from the surface each nozzle protects.

3-4.2.2* The discharge rate for tankside nozzles shall be determined solely on the basis of throw or projection required to cover the surface each nozzle protects.

3-4.3 Area per Nozzle. The maximum area protected by each nozzle shall be determined on the basis of location or projection distance and the design discharge rate in accordance with specific approvals or listings.

3-4.3.1 The same factors used to determine the design discharge rate shall be used to determine the maximum area to be protected by each nozzle.

3-4.3.2 The portion of the hazard protected by individual overhead type nozzles shall be considered as a square area.

3-4.3.3 The portion of the hazard protected by individual tankside or linear nozzles may be either a rectangular or a square area in accordance with spacing and discharge limitations stated in specific approvals or listings.

3-4.3.4 When coated rollers or other similar irregular shapes are to be protected, the projected wetted area may be used to determine nozzle coverage.

3-4.3.5 Where coated surfaces are to be protected, the area per nozzle may be increased by 40 percent over the areas given in specific approvals or listings. Coated surfaces are defined as those designed for drainage which are constructed and maintained so that no pools of liquid will accumulate over a total area exeeeding 10 percent of the protected surface. This subsection does not apply where there is a heavy buildup of residue. (*See 3-1.2.*)

3-4.3.6 Where local application nozzles are used for protection across openings as defined in 2-2.1.3 and 2-2.1.4, the area per nozzle given by specific approval or listing may be increased 20 percent.

3-4.3.7 When deep layer flammable liquid fires are to be protected, a minimum freeboard of 6 in. (152 mm) shall be provided unless otherwise noted in approvals or listings of nozzles.

3-4.4 Location and Number of Nozzles. A sufficient number of nozzles shall be used to adequately cover the entire hazard area on the basis of the unit areas protected by each nozzle.

3-4.4.1 Tankside or linear type nozzles shall be located in accordance with spacing and discharge rate limitations stated in specific approvals or listings.

3-4.4.2 Overhead type nozzles shall be installed perpendicular to the hazard and centered over the area protected by the nozzle. They may also be installed at angles between 45 degrees and 90 degrees from the plane of the hazard surface as prescribed in 3-4.4.3. The height used in determining the necessary flow rate and area coverage shall be the distance from the aiming point on the protected surface to the face of the nozzle measured along the axis of the nozzle.

3-4.4.3 When installed at an angle, nozzles shall be aimed at a point measured from the near side of the area protected by the nozzle, the location of which is calculated by multiplying the fractional aiming factor in Table 3-4.4.3 by the width of the area protected by the nozzle.

Table 3-4.4.3 Aiming Factors for Angular Placement of Nozzles, Based on 6-in. (152-mm) Freeboard

Discharge Angle[1]	Aiming Factor[2]
45–60°	¼
60–75	¼–⅜
75–90	⅜–½
90 (perpendicular)	½ (center)

[1]Degrees from plane of hazard surface.
[2]Fractional amount of nozzle coverage area.

3-4.4.4 Nozzles shall be located so as to be free of possible obstructions that could interfere with the proper projection of the discharged carbon dioxide.

3-4.4.5 Nozzles shall be located so as to develop an extinguishing atmosphere over coated stock extending above a protected surface. Additional nozzles may be required for this specific purpose, particularly if stock extends more than 2 ft (0.6 m) above a protected surface.

3-4.4.6 The possible effects of air currents, winds, and forced drafts shall be compensated for by properly locating nozzles or by providing additional nozzles to adequately protect the outside areas of the hazard.

3-5 Rate by Volume Method.

3-5.1 General. The volume method of system design is used where the fire hazard consists of three-dimensional irregular objects that cannot be easily reduced to equivalent surface areas.

3-5.2 Assumed Enclosure. The total discharge rate of the system shall be based on the volume of an assumed enclosure entirely surrounding the hazard.

3-5.2.1 The assumed enclosure shall be based on an actual closed floor unless special provisions are made to take care of bottom conditions.

3-5.2.2 The assumed walls and ceiling of this enclosure shall be at least 2 ft (0.6 m) from the main hazard unless actual walls are involved and shall enclose all areas of possible leakage, splashing or spillage.

3-5.2.3 No deductions shall be made for solid objects within this volume.

3-5.2.4 A minimum dimension of 4 ft (1.2 m) shall be used in calculating the volume of the assumed enclosure.

3-5.2.5 If the hazard may be subjected to winds or forced drafts, the assumed volume shall be increased to compensate for losses on the windward sides.

3-5.3 System Discharge Rate. The total discharge rate for the basic system shall be equal to 1 lb/min/ft^3 (16kg/min/m^3) of assumed volume.

3-5.3.1* If the assumed enclosure has a closed floor and is partly defined by permanent continuous walls extending at least 2 ft (0.6 m) above the hazard (where the walls are not normally a part of the hazard), the discharge rate may be proportionately reduced to not less than 0.25 lb/min/ft^3 (4kg/min/m^3) for actual walls completely surrounding the enclosure.

3-5.4 Location and Number of Nozzles. A sufficient number of nozzles shall be used to adequately cover the entire hazard volume on the basis of the system discharge rate as determined by the assumed volume.

3-5.4.1 Nozzles shall be located and directed so as to retain the discharged carbon dioxide in the hazard volume by suitable cooperation between nozzles and objects in the hazard volume.

3-5.4.2 Nozzles shall be located so as to compensate for any possible effects of air currents, winds, or forced drafts.

3-5.4.3 The design discharge rates through individual nozzles shall be determined on the basis of location or projection distance in accordance with specific approvals or listings for surface fires.

3-5.4.4 Special purpose nozzles may have discharge rates based on other factors.

3-6 Distribution System.

3-6.1 General. The system shall be designed to provide an effective discharge of carbon dioxide promptly before excessive amounts of heat can be absorbed by materials within the hazard.

3-6.1.1 The carbon dioxide supply shall be located as near to the hazard as practicable and yet not exposed to the fire, and the pipe line shall be as direct as practicable with a minimum number of turns in order to get carbon dioxide to the fire promptly.

3-6.1.2 The system shall be designed for automatic operation except where the authorities having jurisdiction permit manual operation.

3-6.2 Piping Systems. Piping shall be designed in accordance with 1-10.6 to deliver the required rate of application at each nozzle.

3-6.2.1* High pressure storage temperatures may range from 32 °F to 120 °F (0 °C to 67 °C) without requiring special methods of compensating for changing flow rates.

3-6.3 Discharge Nozzles. The nozzles used shall be listed or approved for rate of discharge, effective range, and pattern or area coverage.

3-6.3.1 The equivalent orifice size used in each nozzle shall be determined in accordance with 1-10.5 to match the design discharge rate.

3-6.3.2 Nozzles shall be accurately located and directed in accordance with the system design requirements as covered in Sections 3-4 and 3-5.

Chapter 4 Hand Hose Line Systems

4-1 General Information.

4-1.1 Description. Hand hose line systems consist of a hose reel or rack, hose, and discharge nozzle assembly connected by fixed piping to a supply of carbon dioxide. A separate carbon dioxide supply can be provided for hand hose line use or carbon dioxide can be piped from a central storage unit which may be supplying several hose lines or fixed manual or automatic systems. (*See 1-9.1.1.*)

4-1.2 Uses. Hand hose line systems may be used to supplement fixed fire protection systems or to supplement first aid fire extinguishers for the protection of specific hazards for which carbon dioxide is a suitable extinguishing agent. These systems shall not be used as a substitute for other fixed carbon dioxide fire extinguishing systems equipped with fixed nozzles, except where the hazard cannot adequately or economically be provided with fixed protection. The decision as to whether hose lines are applicable to the particular hazard shall rest with the authority having jurisdiction.

4-1.3 General Requirements. Hand hose line systems shall be installed and maintained in accordance with the applicable requirements of Chapters 1, 2, and 3, except as outlined below.

4-1.4 Safety Requirements. Reference is made to 1-6.2 and A-1-6.2 regarding hazards to personnel due to obscuration of vision and reduction of oxygen concentration below that which will support life, not only in the immediate area of discharge but in adjacent areas to which gas may migrate.

4-2 Hazard Specifications.

4-2.1 Hand hose line systems may be used to combat fires in all hazards covered under Chapter 1, except those which are inaccessible and beyond the scope of manual fire fighting.

4-3 Location and Spacing.

4-3.1 Hand hose line stations shall be placed such that they are easily accessible and within reach of the most distant hazard which they are expected to protect. In general, they shall not be located such that they are exposed to the hazard nor shall they be located inside any hazard area protected by a total flooding system.

4-3.2 Spacing. If multiple hose stations are used, they shall be spaced so that any area within the hazard may be covered by one or more hose lines.

4-4 Carbon Dioxide Requirements.

4-4.1 Rate and Duration of Discharge. The rate and duration of discharge and consequently the amount of carbon dioxide shall be determined by the type and potential size of the hazard. A hand hose line shall have a sufficient quantity of carbon dioxide to permit its use for at least 1 minute.

4-4.2 Provision for Use by Inexperienced Personnel. The possibility of these hose lines being used by inexperienced personnel shall be considered and adequate provision made so that there will be a sufficient supply of carbon dioxide to enable them to effect extinguishment of the hazards that they are likely to encounter.

4-4.3 Where simultaneous use of two or more hose lines is possible, a sufficient quantity of carbon dioxide shall be available to support the maximum number of nozzles that are likely to be used at any one time for at least one minute. All supply piping shall be sized for the simultaneous operation of the number of nozzles that are likely to be used.

4-5 Equipment Specifications.

4-5.1 Hose. Hose lines on systems with high pressure supply shall have a minimum bursting pressure of 5000 psi (344.8 bars) and hose lines of systems with low pressure supply shall have a minimum bursting pressure of 1800 psi (124.1 bars). (*See 1-11.2.7.*)

4-5.2 Discharge Nozzle Assembly. Hose lines shall be equipped with a discharge nozzle assembly which can be easily handled by one man and which contains a quick-opening shutoff valve to control the flow of carbon dioxide through the nozzle and a suitable handle for directing the discharge. The attachment of the discharge nozzle assembly to the hose by means of a swivel connection is desirable for providing more ease of manipulation.

4-5.3 Hose Line Storage. The hose shall be coiled on a hose reel or rack such that it will be ready for immediate use without the necessity of coupling, and such that it may be uncoiled with a minimum of delay. If installed outdoors, it shall be protected against the weather.

4-5.4 Charging the Hose Line. Operation of hand hose line systems depends upon manual actuation and manual manipulation of a discharge nozzle. Speed and simplicity of operation are therefore essential for successful extinguishment.

4-5.4.1 All controls for actuating the system shall be located in the immediate vicinity of the hose reel.

4-5.4.2 The carbon dioxide supply shall be located as close to the hose reel as possible so that liquid carbon dioxide will be supplied to the hose line with a minimum of delay after actuation.

NOTE: Bleeder valves or similar devices may be utilized to reduce delay in obtaining liquid discharge on low pressure systems.

4-5.4.3 Except when in actual use, pressure shall not be permitted to remain in the hose line.

4-6 Training. Successful extinguishment of fire with hand hose lines is greatly dependent upon the individual ability and technique of the operator. All personnel who are likely to use this equipment at the time of a fire shall be properly trained in its operation and in the fire fighting techniques applicable to this equipment.

Chapter 5 Standpipe Systems and Mobile Supply

5-1 General Information.

5-1.1 Description. A standpipe system is a fixed total flooding, local application, or hand hose line system without a permanently connected carbon dioxide supply. The carbon dioxide supply is mounted on a mobile vehicle which can be towed or driven to the scene of a fire and quickly coupled to the standpipe system protecting the involved hazard. Mobile supply is primarily fire brigade or fire department equipment requiring trained personnel for effective use.

5-1.2 Uses. Standpipe systems and mobile supply may be used to supplement complete fixed fire protection systems or may be used alone for the protection of the specific hazards outlined below. Mobile supply may be used as a reserve to supplement a fixed supply. Mobile supply may also be outfitted with hand hose lines for the protection of scattered hazards. These systems shall be installed only with the approval of the authority having jurisdiction.

5-1.3 General Requirements. Standpipe systems and mobile supply shall be installed and maintained in accordance with the requirements in Chapters 1, 2, 3, and 4, in addition to those outlined below. Piping shall be installed in accordance with the requirements applicable for the system if a permanently connected supply is used. Appreciable lengths of piping on the portable supply shall be taken into account.

5-2 Hazard Specifications.

5-2.1 Standpipe systems and mobile supply may be used to protect hazards included in Chapters 1, 2, 3, and 4, where extinguishment will not be adversely affected by the delay in obtaining effective discharge of carbon dioxide while the mobile supply is being brought to the scene and coupled to the standpipe system.

5-3 Standpipe Requirements.

5-3.1 The supply piping of standpipe systems shall be equipped with quick-change couplings and shall terminate in an easily accessible and well-marked location for connection to the mobile supply. This location shall also be marked with the amount of carbon dioxide required and the required duration of discharge.

5-4 Mobile Supply Requirements.

5-4.1 Capacity. The mobile supply shall have a capacity in accordance with the provisions of Chapters 1, 2, 3, and 4. Extra quantities may be required to compensate for delay in getting the mobile supply to the hazard.

5-4.2 Coupling. The mobile supply shall be provided with suitable means for transferring carbon dioxide into the standpipe system. Quick-change couplings shall be provided to permit these connections to be made as rapidly as possible.

5-4.3 Mobility. The storage container or containers of carbon dioxide shall be mounted on a movable vehicle which may be brought to the scene of the fire by manual means, by a separate motor vehicle, or under its own power. The means of transporting the mobile supply shall be dependable and capable of getting to the fire with a minimum of delay.

5-4.4 Location. The mobile supply shall be kept close at hand to the hazards it is intended to protect in order that fire extinguishment may be started as soon as possible after the fire breaks out.

5-4.5 Accessories. Mobile supply for standpipe systems may be provided with hand hose lines as accessory equipment for the protection of small scattered hazards, or as a supplement to standpipe systems or other fixed protection.

5-5 Training. The effectiveness of fire protection provided by standpipe systems and mobile supply depends upon the efficiency and ability of the manpower which handles the mobile supply. It is therefore imperative that those persons assigned to the units shall be properly trained in its use and maintenance. Generally, this equipment is in the category of fire brigade or fire department equipment requiring a regularly assigned crew.

Chapter 6 Referenced Publications

6-1 The following documents or portions thereof are referenced within this standard and shall be considered part of the requirements of this document. The edition indicated for each reference is the current edition as of the date of the NFPA issuance of this document.

6-1.1 NFPA Publications. National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

NFPA 70-1987, *National Electrical Code*

NFPA 71-1987, *Standard for the Installation, Maintenance, and Use of Central Station Signaling Systems*

NFPA 72A-1987, *Standard for the Installation, Maintenance, and Use of Local Protective Signaling Systems for Guard's Tour, Fire Alarm, and Supervisory Service*

NFPA 72C-1986, *Standard for the Installation, Maintenance, and Use of Remote Station Protective Signaling Systems*

NFPA 72D-1986, *Standard for the Installation, Maintenance, and Use of Proprietary Protective Signaling Systems.*

6-1.2 Other Publications.

6-1.2.1 ASTM Publications. American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

ASTM A53-1982, *Specifications for Welded and Seamless Pipe*

ASTM A106-1982, *Specifications for Seamless Carbon Steel Pipe for High-Temperature Service*

ASTM E380-1986, *Standard for Metric Practice.*

6-1.2.2 ASME Publication. American Society of Mechanical Engineers, East 47th Street, New York, NY 10017.

ASME, API-ASME, *Code for Unfired Pressure Vessels for Petroleum Liquids and Gases.*

6-1.2.3 US Government Publications. US Government Printing Office, Washington, DC 20401.

DOT, *Title 49, Transportation, Code of Federal Regulations*, Parts 171-190 (DOT)

Bureau of Mines 627-1962.

6-1.2.4 ANSI Publication. American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.

ANSI B-31.1-1980, *Power Piping Code.*

Appendix A

This Appendix is not a part of the requirements of this NFPA document but, is included for information purposes only.

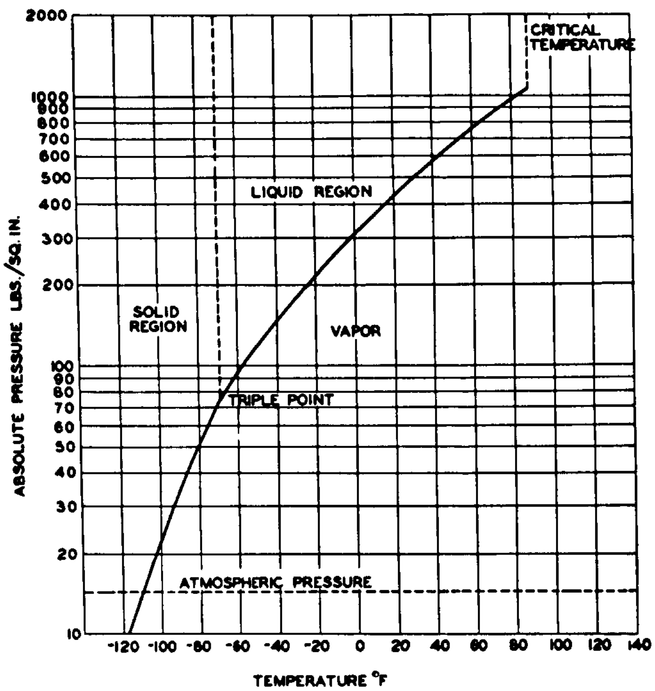
The following notes, bearing the same number as the text of the *Standard on Carbon Dioxide Extinguishing Systems* to which they apply, contain useful explanatory material and references to standards.

A-1-5.2 Carbon Dioxide. Carbon dioxide is a standard commercial product with many uses. It is perhaps most familiar as the gas that gives the "tingle" in soda pop and other carbonated beverages. In other industrial applications it may be used for its chemical properties, for its mechanical properties as a pressurizing agent, or for its refrigerating properties as dry ice.

For fire extinguishing applications, carbon dioxide has a number of desirable properties. It is noncorrosive, nondamaging and leaves no residue to clean up after the fire. It provides its own pressure for discharge through pipes and nozzles. Since it is a gas, it will penetrate and spread to all parts of a hazard. It will not conduct electricity and can therefore be used on live electrical hazards. It can be effectively used on practically all combustible materials except for a few active metals and metal hydrides, and materials such as cellulose nitrate, which contain available oxygen.

Under normal conditions carbon dioxide is an odorless, colorless gas with a density about 50 percent greater than the density of air. Many people insist they can detect an odor of carbon dioxide, but this may be due to impurities or chemical effects in the nostrils. Carbon dioxide is easily liquefied by compression and cooling. By further cooling and expansion it can be converted to the solid state.

The relationship between the temperature and the pressure of liquid carbon dioxide is shown on the curve given in Figure A-1-5.2. It will be noted that as the temperature of the liquid increases, the pressure also increases. As the pressure increases, the density of the vapor over the liquid increases. On the other hand, the liquid expands as the temperature goes up and its density decreases. At 87.8 °F (31 °C) the liquid and vapor have the same density, and of course the liquid phase disappears. This is called the critical temperature for carbon dioxide.



For SI Units: 1 psi = 0.0689 bars; °C = 5/9 (°F − 32).

Figure A-1-5.2 Variation of Pressure of Carbon Dioxide with Change in Temperature (Constant Volume). Below the critical temperature (87.8 °F) (31 °C), carbon dioxide in a closed container is part liquid and part gas. Above the critical temperature it is entirely gas.

An unusual property of carbon dioxide is the fact that it cannot exist as a liquid at pressures below 60 psi gauge [75 psi absolute (5.2 bars)]. This is the triple point pressure where carbon dioxide may be present as a solid, liquid, or vapor. Below this pressure it must be either a solid or gas, depending on the temperature.

If the pressure in a storage container is reduced by bleeding off vapor, some of the liquid will vaporize and the remaining liquid will become colder. At 60 psi [75 psi absolute (5.2 bars)] the remaining liquid will be converted to dry ice at a temperature of −69 °F (−56 °C). Further reduction in the pressure to atmospheric will lower the temperature of the dry ice to the normal −110 °F (−79 °C).

The same process takes place when discharging liquid carbon dioxide to the atmosphere. A large portion of the liquid flashes to vapor with a considerable increase in volume. The rest is converted to finely divided particles of dry ice at −110 °F (−79 °C). It is this dry ice or snow that gives the discharge its typical white cloudy appearance. The low temperature also causes the condensation of water from the entrained air so that ordinary water fog tends to persist for a while after the dry ice has evaporated.

A-1-5.3.4 While carbon dioxide will not extinguish these fires, it will not react dangerously with these materials or increase their burning rate. Carbon dioxide, if used in this type of situation in a total flooding system, will provide protection for adjacent combustibles or can be successfully used if the reactive metals or hydride are first covered by another material. Examples of this later condition would be:

(a) Sodium stored or used under kerosene

(b) Cellulose nitrate in solution of lacquer thinner

(c) Magnesium chips covered with heavy oil.

Local application systems with attendant high velocity directed discharge should not be used.

A-1-6 Safety Requirements. The steps and safeguards necessary to prevent injury or death to personnel in areas whose atmospheres will be made hazardous by the discharge of carbon dioxide may include the following:

(a) Provision of adequate aisleways and routes of exit and keeping them clear at all times.

(b) Provision of the necessary additional or emergency lighting, or both, and directional signs to ensure quick, safe evacuation.

(c) Provision of alarms within such areas that will operate immediately upon activation of the system on detection of the fire, with the discharge of the carbon dioxide and the activation of automatic door closures delayed for sufficient time to evacuate the area before discharge begins.

(d) Provision of only outward swinging, self-closing doors at exits from hazardous areas, and where such doors are latched, provision of panic hardware.

(e) Provision of continuous alarms at entrances to such areas until atmosphere has been restored to normal.

(f) Provision for adding an odor to the carbon dioxide so that hazardous atmospheres in such areas may be recognized.

(g) Provision of warning and instruction signs at entrances to and inside such areas.

(h) Provision for prompt discovery and rescue of persons rendered unconscious in such areas. This may be accomplished by having such areas searched immediately after carbon dioxide discharge stops by trained personnel equipped with proper breathing equipment. Those rendered unconscious by carbon dioxide can be restored without permanent injury by artificial respiration, if removed quickly from the hazardous atmosphere. Self-contained breathing equipment and personnel trained in its use, and in rescue practices including artificial respiration, should be readily available.

(i) Provision of instruction and drills of all personnel within or in the vicinity of such areas, including maintenance or construction people who may be brought into the area, to ensure their correct action when carbon dioxide protective equipment operates.

(j) Provision of means for prompt ventilation of such areas. Forced ventilation will often be necessary. Care should be taken to really dissipate hazardous atmospheres and not merely move them to another location. Carbon dioxide is heavier than air.

(k) Provision of such other steps and safeguards necessary to prevent injury or death as indicated by a careful study of each particular situation.

A-1-7.3 Where piping is not normally under pressure, it may not be bubbletight. However, where a slow discharge is involved, or if under continual pressure, bubbletightness should be a requirement. It is anticipated that full discharge tests will be waived by the authority having jurisdiction only under extremely unusual conditions. Factors such as extra cost, interruptions to production, or business operations are not considered to be valid reasons for waiver of full discharge tests.

A-1-8.2.2 For additional information on detectors refer to NFPA 72E, *Standard on Automatic Fire Detectors*.

A-1-8.3.6 It is not the intent of this standard to prohibit the use of more pilot cylinders than the minimum number required in this paragraph.

A suggested method of cylinder arrangement for three or more cylinders is to locate a slave cylinder at the farthest point (No. 1 position) from the manifold outlet, and the two or more pilot cylinders located in the next two or more positions (Nos. 2, 3, etc.) numbering toward the manifold outlet. Actuation of the remaining pilot cylinder(s) should provide sufficient pressure in the manifold to actuate the slave cylinders and all other pressure actuated devices and interlocks.

A-1-8.5.2 Alarm(s) should be connected to existing protective signaling (fire alarm) system(s) to aid life safety and property protection as outlined in NFPA 71, *Standard for the Installation, Maintenance, and Use of Central Station Signaling Systems*; NFPA 72A, *Standard for the Installation, Maintenance, and Use of Local Protective Signaling Systems for Guard's Tour, Fire Alarm, and Supervisory Service*; NFPA 72B, *Standard for the Installation, Maintenance, and Use of Auxiliary Protective Signaling Systems*; NFPA 72C, *Standard for the Installation, Maintenance, and Use of Remote Station Protective Signaling Systems*; NFPA 72D, *Standard for the Installation, Maintenance, and Use of Proprietary Protective Signaling Systems*; and NFPA *101®, Life Safety Code®*.

A-1-8.6 See NFPA 72A, *Standard for the Installation, Maintenance, and Use of Local Protective Signaling Systems for Guard's Tour, Fire Alarm, and Supervisory Service*, paragraph 2-3.4, for typical examples of standby power.

A-1-9.1 Not all of the carbon dioxide in the low pressure container can be rapidly discharged. As the storage container becomes empty a quantity of cold carbon dioxide vapor will remain in the container. The quantity of this residual vapor will vary depending on the physical configuration of the container. This residual vapor should be considered in determining the storage capacity.

A-1-9.2 Carbon Dioxide Quality. Carbon dioxide, as normally manufactured, is an extremely pure product. In general, the industry produces only one grade or quality. This grade is considered suitable for all applications, including food and medical uses.

Dry carbon dioxide gas or liquid is completely noncorrosive to the containers. Carbon dioxide containing excess water may cause some corrosion in high pressure cylinders, particularly in the lightweight cylinders that are highly stressed. Excess water is present when the amount exceeds the normal solubility in liquid carbon dioxide, so that actual water may condense out on the walls of the container.

Carbon dioxide produced in modern low pressure plants must necessarily have a very low water content to avoid operating difficulties. The normal practice is to maintain the water content below about 0.01 percent by weight. If this dry product is stored and transported in clean bulk low pressure equipment, the quality will be maintained until it is used.

Dry ice normally contains more water and oil than does liquid carbon dioxide. It also tends to freeze moisture and other impurities from the atmosphere, because of its very low temperature of −110 °F (−79 °C). When dry ice is placed in a converter and allowed to warm up so that it becomes liquid carbon dioxide, the liquid so produced will obviously contain an excess amount of water. This liquid should not be used to charge fire extinguishing cylinders, unless it is further processed through a dehydrating unit to remove the excess water. It should also be noted that such dehydrating units may become ineffective unless the drying agent is renewed or reactivated as necessary to maintain its drying ability.

There are still a few high pressure carbon dioxide production plants in service. The carbon dioxide produced in these plants may also contain excess water, unless the dehydrating equipment is kept in good condition. The only positive way to be assured of proper quality is to periodically analyze the carbon dioxide supply used for charging fire protection systems.

A-1-9.5 High Pressure Storage Containers. In high pressure storage systems the temperature of the contained carbon dioxide will depend on the ambient temperature at the storage location. The containers must therefore be capable of withstanding the pressures developed at the highest expected temperature.

The maximum pressure in the cylinder is also affected by the filling density or percent filling. This is the ratio expressed in percent of the carbon dioxide weight to the water capacity in pounds. The filling density commonly used is between 60 and 68 percent, the latter being the maximum allowed by the US Department of Transportation.[1] Proper filling is determined by weight stamped on the valve body.

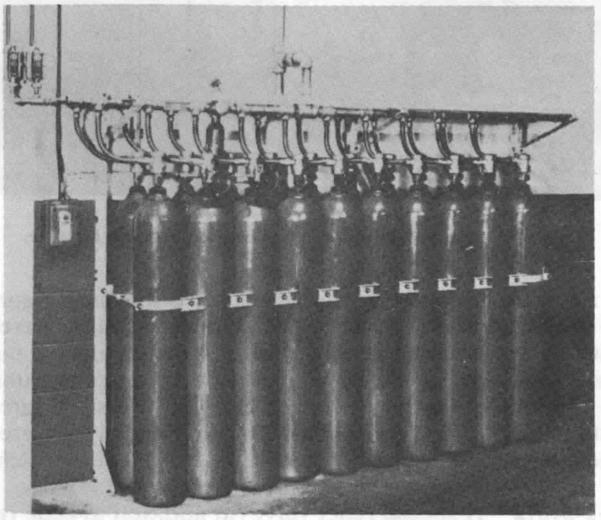


Figure A-1-9.5 A Typical High Pressure Storage Facility.

[1]Sec. 173.308 of Title 49, Transportation, Code of Federal Regulations. Parts 171-190 (DOT). Available from the Superintendent of Documents, US Government Printing Office, Washington, DC 20401.

A typical high pressure storage facility using a number of cylinders is shown in Figure A-1-9.5. Flexible connectors are used between each cylinder and the common manifold. This is to facilitate the problem of check-weighing cylinders and replacing cylinders after use. Each cylinder is provided with its own valve with a dip tube extending to the bottom. Some older types of cylinders do not have dip tubes and are installed upside down to ensure discharge of liquid carbon dioxide.

A-1-9.6 Low Pressure Storage Containers. In low pressure storage systems the temperature of the contained carbon dioxide is controlled at about 0 °F (− 18 °C) by means of insulation and refrigeration. The normal pressure is thus maintained at about 300 psi (20.7 bars). Welded pressure vessels are used for this service, and there is no special limitation so far as size is concerned.

The filling density will have no effect on the pressure so long as there is sufficient vapor space to allow for expansion of the liquid at the maximum storage temperature and pressure. This would be determined by the setting or the pressure relief valves. In general, the filling density may range from 90 to 95 percent. The maximum liquid level is controlled, when filling, by means of a short dip tube which returns excess liquid to the delivery unit when the liquid reaches the maximum filling level in the storage unit. A liquid level gage is also provided to indicate the quantity of carbon dioxide in storage.

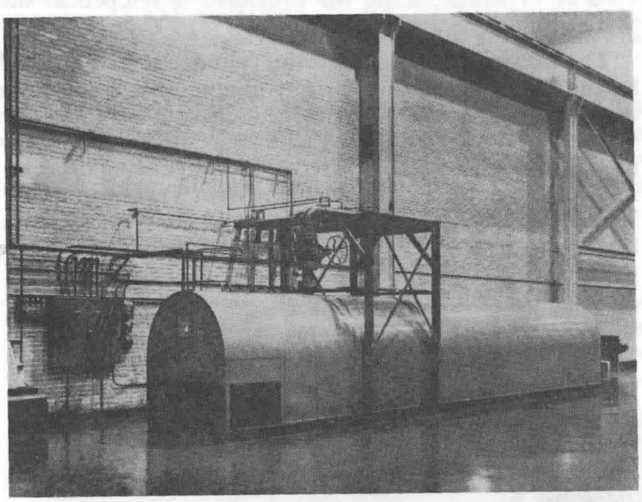


Figure A-1-9.6 A Typical Low Pressure Storage Facility.

A typical low pressure storage facility is shown in Figure A-1-9.6. In this unit the insulated pressure vessel is covered with an outer metal housing which is sealed to keep out water moisture. A standard air-cooled refrigeration unit is mounted at one end, with its cooling coils mounted within the pressure vessel. This unit is electrically powered and automatically controlled by means of a pressure switch.

A-1-9.6.2 A special relief valve (in addition to code requirements) may be provided for controlled bleed-off at a pressure below the setting of the main safety valve.

A-1-10.1.1 The use of flexible piping or hoses in a carbon dioxide system introduces a number of things to be considered that do not affect rigid piping. One of these is the nature of any changes of direction. The minimum radius of curvature for any flexible hose to be used in a carbon dioxide system should not be less than indicated by the manufacturer's data, usually shown in the listing information for a particular system. Other areas of concern are resistance to the effects of vibration, flexure, tension, torsion, temperature, flame, compression, and bending. It is also necessary for the hose to have the strength to contain the carbon dioxide during discharge, and be made of materials that will be resistant to atmospheric corrosion.

A-1-10.2.1 A dirt trap consisting of a tee with a capped nipple, at least 2 in. (51 mm) long, should be installed at the end of each pipe run.

A-1-10.4.4 Formerly, a plus sign following the orifice code number indicated equivalent diameters 1/64 in.(0.4 mm) greater than that indicated by the numbering system [e.g., No. 4 indicated an equivalent diameter of 4/32 in. (3.18 mm); a No. 4 + , 9/64 in. (3.57 mm.)]

A-1-10.5 Pipe and Orifice Size Determination. The problem of computing pipe sizes for carbon dioxide systems is complicated by the fact that the pressure drop is nonlinear with respect to the pipeline. Carbon dioxide leaves the storage vessel as a liquid at saturation pressure. As the pressure drops because of pipeline friction, the liquid boils so as to produce a mixture of liquid and vapor. Because of this the volume of the flowing mixture increases and the velocity of flow must also increase. Thus, the pressure drop per unit length of pipe is greater near the end of the pipeline than it is at the beginning.

Pressure drop information for designing piping systems can best be obtained from curves of pressure versus equivalent length for various flow rates and pipe sizes. Such curves can be plotted using the theoretical equation given in 1-10.5.1. The Y and Z factors in the equation depend on storage pressure and line pressure. These can be evaluated from the following equations:

$$Y = -\int_{P_1}^{P} \rho \, dP$$

$$Z = -\int_{\rho_1}^{\rho} \frac{d\rho}{\rho} = \ln \frac{\rho_1}{\rho}$$

Where P_1 = Storage pressure in psia
P = Pressure at end of pipeline in psia
ρ_1 = Density at pressure P_1 in lbs/ft³
ρ = Density at pressure P in lbs/ft³
ln = Natural logarithm

For SI Units

$$Y = -\int_{P_1}^{P} \rho \, dP$$

$$Z = -\int_{\rho_1}^{\rho} \frac{d\rho}{\rho} = \ln \frac{\rho_1}{\rho}$$

Where P_1 = Storage pressure in bar
P = Pressure at end of pipeline in bar
ρ_1 = Density at pressure P_1 in kgs m^3
ρ = Density at pressure P in kgs m^3
ln = Natural logarithm

In the above equations Z is a dimensionless ratio. The Y factor has units of pressure times density and will therefore change the system of units.

The storage pressure is an important factor in carbon dioxide flow. In low pressure storage the starting pressure in the storage vessel will recede to a lower level depending on whether all or only a part of the supply is discharged. Because of this, the average pressure during discharge will be about 285 psi (19.7 bars). The flow equation is based on absolute pressure; therefore, 300 psia (20.7 bars) is used for calculations involving low pressure systems.

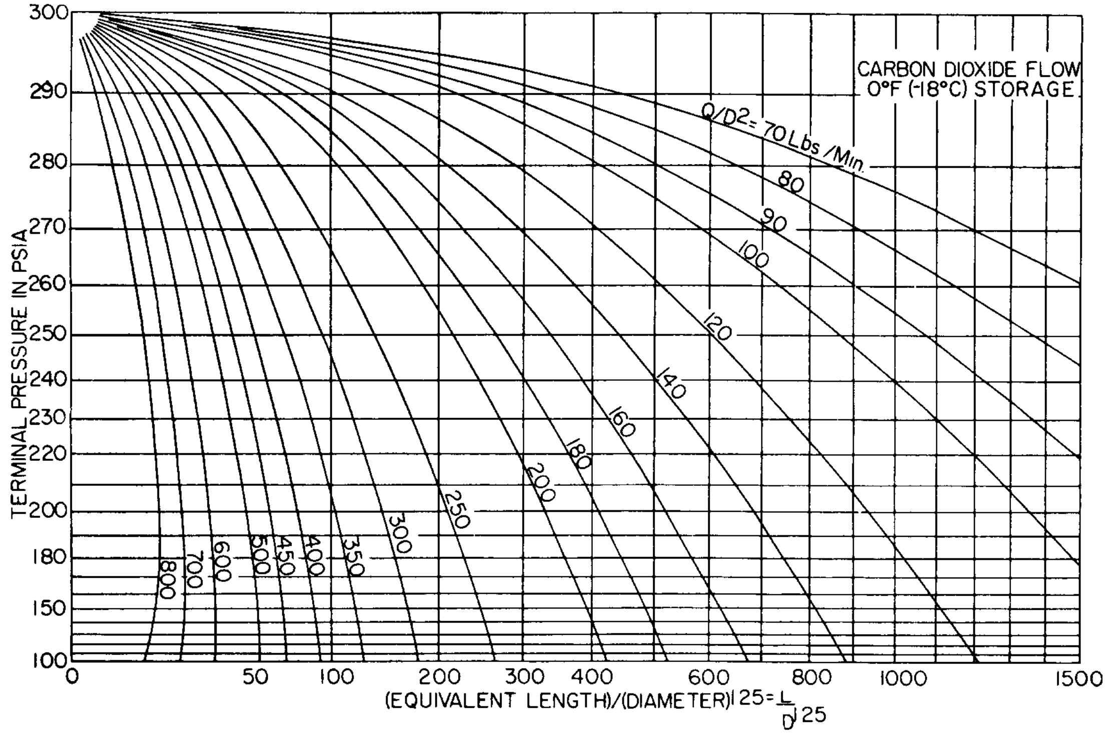


Figure A-1-10.5(A) Pressure Drop in Pipeline for 300 psia (20.7 bars) Storage Pressure.

SI Units: 1 psia = 0.0689 bar; 1 lb/min = 0.454 kg/min.

Table A-1-10.5(a)
Values of Y and Z for 300 psia Initial Storage Pressure

Pressure psia	Z	Y 0	1	2	3	4	5	6	7	8	9
300	.000	0	0	0	0	0	0	0	0	0	0
290	.135	596	540	483	426	367	308	248	187	126	63
280	.264	1119	1070	1020	969	918	866	814	760	706	652
270	.387	1580	1536	1492	1448	1402	1357	1310	1263	1216	1168
260	.505	1989	1950	1911	1871	1831	1790	1749	1708	1666	1623
250	.620	2352	2318	2283	2248	2212	2176	2139	2102	2065	2027
240	.732	2677	2646	2615	2583	2552	2519	2487	2454	2420	2386
230	.841	2968	2940	2912	2884	2855	2826	2797	2768	2738	2708
220	.950	3228	3204	3179	3153	3128	3102	3075	3049	3022	2995
210	1.057	3462	3440	3418	3395	3372	3349	3325	3301	3277	3253
200	1.165	3673	3653	3632	3612	3591	3570	3549	3528	3506	3485
190	1.274	3861	3843	3825	3807	3788	3769	3750	3731	3712	3692
180	1.384	4030	4014	3998	3981	3965	3948	3931	3914	3896	3879
170	1.497	4181	4167	4152	4138	4123	4108	4093	4077	4062	4046
160	1.612	4316	4303	4291	4277	4264	4251	4237	4223	4210	4196
150	1.731	4436	4425	4413	4402	4390	4378	4366	4354	4351	4329

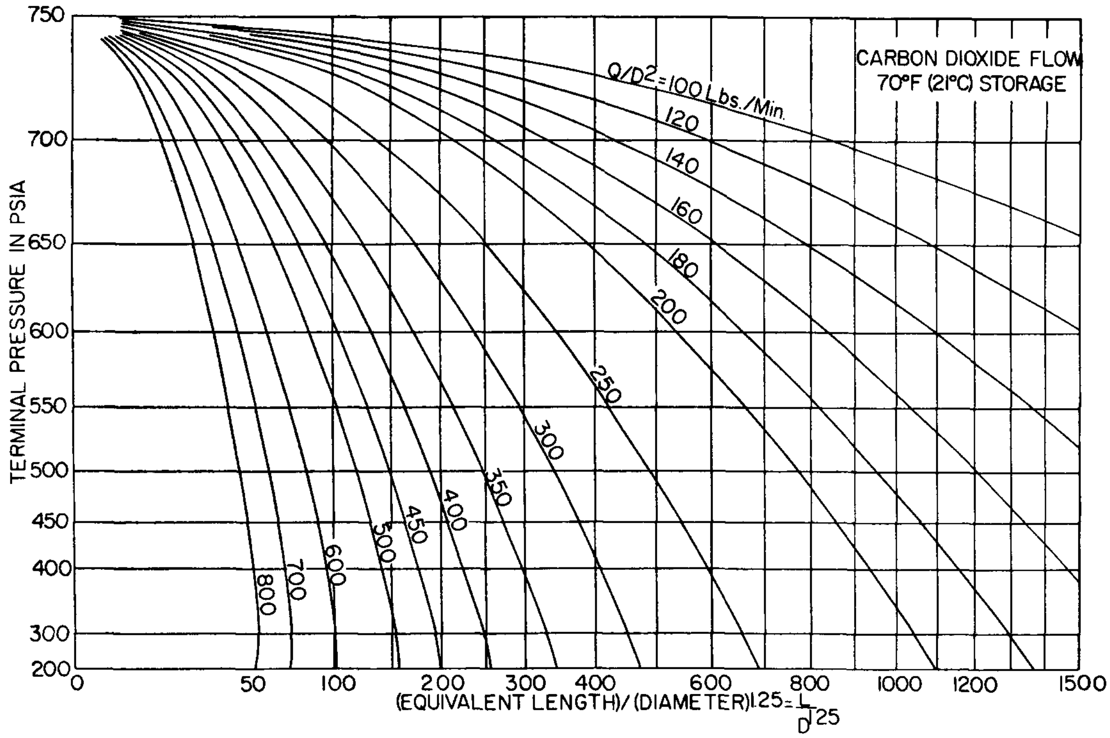


Figure A-1-10.5(B) Pressure Drop in Pipeline for 750 psia .7 bars) Storage Pressure.

SI Units: 1 psia = 0.0689 bar; 1 lb/min = 0.454 kg/min.

In high pressure systems the storage pressure depends on the ambient temperature. Normal ambient temperature is assumed to be 70 °F (21 °C). For this condition the average pressure in the cylinder during discharge of the liquid portion will be about 750 psia (51.7 bars). This pressure has therefore been selected for calculations involving high pressure systems.

Using the above base pressures of 300 psia (20.7 bars) and 750 psia (51.7 bars), values have been determined for the Y and Z factors in the flow equation. These are listed in Tables A-1-10.5(a) and A-1-10.5(b).

For practical application it is desirable to plot curves for each pipe size that may be used. However, it will be noted that the flow equation can be rearranged as given below.

$$\frac{L}{D^{1.25}} = \frac{3647\ Y}{(Q/D^2)^2} - 8.08\ Z$$

Thus by plotting values of $L/D^{1.25}$ and Q/D^2, it is possible to use one family of curves for any pipe size. Figure A-1-10.5(A) gives flow information for 0 °F (−18 °C) storage temperature on this basis. Figure A-1-10.5(B) gives similar information for high pressure storage at 70 °F (21 °C). For an inside pipe diameter of exactly 1 in., D^2 and $D^{1.25}$ reduce to unity and cancel out. For other pipe sizes it is necessary to convert the flow rate and equivalent length by dividing or multiplying by these factors. Table A-1-10.5(a) gives values for D.

These curves can be used for designing systems or for checking possible flow rates. For example, assume the problem is to determine the terminal pressure for a low pressure system consisting of a single 2-in. Schedule 40 pipeline with an equivalent length of 500 ft and a flow rate of 1,000 lb/min. The flow rate and the equivalent length must be converted to terms of Figure A-1-10.5(A) as follows:

$$\frac{Q}{D^2} = \frac{1000}{4.28} = 234\ \text{lbs/min}/D^2$$

$$\frac{L}{D^{1.25}} = \frac{500}{2.48} = 201\ \text{ft}/D^{1.25}$$

From Figure A-1-10.5(A) the terminal pressure is found to be about 228 psia at the point where the interpolated flow rate of 234 lb/minute intersects the equivalent length scale at 201 ft.

If this line terminates in a single nozzle, the equivalent orifice area must be matched to the terminal pressure in order to control the flow rate at the desired level of 1,000 lb/min. Referring to Table 1-10.4.4(b) of 1-10.5.2, it will be noted that the discharge rate will be 1,410 lb/min/in.^{2} of equivalent orifice area when the orifice pressure is 230 psia. The required equivalent orifice area of the nozzle is thus equal to the total flow rate divided by the rate per in.^{2}

$$\text{Equivalent Orifice Area} = \frac{1{,}000\ \text{lbs/min}}{1{,}410\ \text{lbs/min/in.}^2} = 0.709\ \text{in.}^2$$

From a practical viewpoint the designer would select a standard nozzle having an equivalent area nearest to the computed area. If the orifice area happened to be a little larger, the actual flow rate would be slightly higher and the terminal pressure would be somewhat lower than the estimated 228 psia (15.7 bars).

Table A-1-10.5(b)
Values of Y and Z for 750 psia Initial Storage Pressure

Pressure psia	Z	Y 0	1	2	3	4	5	6	7	8	9
750	.000	0	0	0	0	0	0	0	0	0	
740	.038	497	448	399	350	300	251	201	151	101	51
730	.075	975	928	881	833	786	738	690	642	594	545
720	.110	1436	1391	1345	1299	1254	1208	1161	1115	1068	1022
710	.143	1882	1838	1794	1750	1706	1661	1616	1572	1527	1481
700	.174	2314	2271	2229	2186	2143	2100	2057	2013	1970	1926
690	.205	2733	2691	2650	2608	2567	2525	2483	2441	2399	2357
680	.235	3139	3099	3059	3018	2978	2937	2897	2856	2815	2774
670	.265	3533	3494	3455	3416	3377	3338	3298	3259	3219	3179
660	.296	3916	3878	3840	3802	3764	3726	3688	3649	3611	3572
650	.327	4286	4250	4213	4176	4139	4102	4065	4028	3991	3953
640	.360	4645	4610	4575	4539	4503	4467	4431	4395	4359	4323
630	.393	4993	4959	4924	4890	4855	4821	4786	4751	4716	4681
620	.427	5329	5296	5263	5229	5196	5162	5129	5095	5061	5027
610	.462	5653	5621	5589	5557	5525	5493	5460	5427	5395	5362
600	.498	5967	5936	5905	5874	5843	5811	5780	5749	5717	5685
590	.535	6268	6239	6209	6179	6149	6119	6089	6058	6028	5997
580	.572	6560	6531	6502	6473	6444	6415	6386	6357	6328	6298
570	.609	6840	6812	6785	6757	6729	6701	6673	6645	6616	6588
560	.646	7110	7084	7057	7030	7003	6976	6949	6922	6895	6868
550	.683	7371	7345	7320	7294	7268	7242	7216	7190	7163	7137
540	.719	7622	7597	7572	7548	7523	7498	7472	7447	7422	7396
530	.756	7864	7840	7816	7792	7768	7744	7720	7696	7671	7647
520	.792	8098	8075	8052	8028	8005	7982	7958	7935	7911	7888
510	.827	8323	8301	8278	8256	8234	8211	8189	8166	8143	8120
500	.893	8540	8519	8497	8476	8454	8433	8411	8389	8367	8345
490	.898	8750	8730	8709	8688	8667	8646	8625	8604	8583	8562
480	.933	8953	8933	8913	8893	8873	8852	8832	8812	8791	8771
470	.967	9149	9129	9110	9091	9071	9052	9032	9012	8993	8973
460	1.002	9338	9319	9301	9282	9263	9244	9225	9206	9187	9168
450	1.038	9520	9502	9484	9466	9448	9430	9412	9393	9375	9356
440	1.073	9697	9679	9662	9644	9627	9609	9592	9574	9556	9538
430	1.109	9866	9850	9833	9816	9799	9782	9765	9748	9731	9714
420	1.146	10 030	10 014	9998	9982	9966	9949	9933	9916	9900	9883
410	1.184	10 188	10 173	10 157	10 141	10 126	10 110	10 094	10 078	10 062	10 046
400	1.222	10 340	10 325	10 310	10 295	10 280	10 265	10 250	10 234	10 219	10 204
390	1.262	10 486	10 472	10 458	10 443	10 429	10 414	10 399	10 385	10 370	10 355
380	1.302	10 627	10 613	10 599	10 585	10 571	10 557	10 543	10 529	10 515	10 501
370	1.344	10 762	10 749	10 735	10 722	10 708	10 695	10 681	10 668	10 654	10 641
360	1.386	10 891	10 878	10 866	10 853	10 840	10 827	10 814	10 801	10 788	10 775
350	1.429	11 015	11 003	10 991	10 978	10 966	10 954	10 941	10 929	10 916	10 904
340	1.473	11 134	11 122	11 110	11 099	11 087	11 075	11 063	11 051	11 039	11 027
330	1.518	11 247	11 236	11 225	11 214	11 202	11 191	11 180	11 168	11 157	11 145
320	1.564	11 356	11 345	11 334	11 323	11 313	11 302	11 291	11 280	11 269	11 258
310	1.610	11 459	11 449	11 439	11 428	11 418	11 408	11 398	11 387	11 377	11 366
300	1.657	11 558	11 548	11 539	11 529	11 519	11 509	11 499	11 489	11 479	11 469

If, in the previous example, instead of terminating with one large nozzle, the pipeline branches into two smaller pipelines, it will be necessary to determine the pressure at the end of each branch line. To illustrate this procedure, assume that the branch lines are equal and consist of 1½-in. Schedule 40 pipe with equivalent lengths of 200 ft (61 m) and the flow in each branch line is to be 500 lb/min (227/kg/min). Converting to terms used in Figure A-1-10.5(A):

$$\frac{Q}{D^2} = \frac{500}{2.592} = 193 \text{ lbs/min}/D^2$$

$$\frac{L}{D^{1.25}} = \frac{200}{1.813} = 110 \text{ ft}/D^{1.25}$$

Table A-1-10.5(a) (Metric)
Values of Y and Z for 20.7 bar Initial Storage Pressure

Pressure bar	Z	Y 0	.1	.2	.3	.4	.5	.6	.7	.8	.9
20	.134	652	562	470	377	282	185	86	0	0	0
19	.319	1468	1393	1317	1239	1160	1079	997	913	828	741
18	.493	2152	2088	2024	1959	1893	1825	1756	1686	1615	1542
17	.659	2727	2674	2619	2564	2508	2451	2393	2334	2274	2214
16	.819	3215	3169	3123	3076	3029	2981	2931	2882	2831	2779
15	.976	3631	3592	3553	3513	3472	3431	3389	3346	3303	3259
14	1.132	3987	3954	3920	3886	3851	3816	3780	3743	3706	3669
13	1.290	4292	4264	4235	4205	4176	4145	4115	4083	4052	4020
12	1.451	4553	4529	4504	4479	4453	4428	4401	4375	4348	4320
11	1.618	4774	4754	4733	4712	4690	4668	4646	4623	4600	4577
10	1.792	4960	4943	4926	4908	4890	4871	4853	4834	4814	4794

Table A-1-10.5(b) (Metric)
Values of Y and Z for 51.7 bar Initial Storage Pressure

Pressure psia	Z	Y 0	.1	.2	.3	.4	.5	.6	.7	.8	.9
51	.028	563	485	407	329	250	170	91	11	0	0
50	.085	1321	1247	1172	1097	1022	946	871	794	718	640
49	.133	2045	1974	1903	1831	1759	1687	1615	1542	1469	1395
48	.179	2736	2669	2601	2532	2464	2395	2325	2256	2186	2115
47	.223	3397	3332	3267	3202	3136	3070	3004	2938	2871	2804
46	.267	4027	3966	3903	3841	3779	3716	3652	3589	3525	3461
45	.313	4629	4570	4511	4452	4392	4332	4271	4211	4150	4089
44	.361	5203	5147	5090	5034	4977	4920	4862	4804	4746	4688
43	.411	5750	5696	5643	5589	5534	5480	5425	5370	5315	5259
42	.462	6271	6220	6168	6117	6065	6013	5961	5909	5856	5803
41	.515	6766	6717	6669	6620	6571	6521	6472	6422	6372	6321
40	.568	7236	7190	7144	7098	7051	7004	6957	6909	6862	6814
39	.622	7683	7639	7596	7552	7507	7463	7418	7373	7328	7282
38	.676	8107	8066	8024	7982	7940	7898	7855	7813	7770	7727
37	.729	8510	8470	8431	8391	8351	8311	8271	8230	8189	8148
36	.782	8891	8854	8816	8779	8741	8703	8665	8626	8588	8549
35	.834	9253	9218	9182	9146	9111	9074	9038	9002	8965	8928
34	.885	9596	9563	9529	9495	9461	9427	9392	9358	9323	9288
33	.936	9922	9890	9858	9826	9793	9761	9728	9696	9663	9629
32	.987	10 230	10 200	10 170	10 139	10 109	10 078	10 047	10 016	9985	9953
31	1.038	10 523	10 495	10 466	10 437	10 408	10 379	10 349	10 320	10 290	10 260
30	1.090	10 801	10 774	10 747	10 720	10 692	10 664	10 636	10 608	10 580	10 552
29	1.143	11 065	11 040	11 014	10 988	10 961	10 935	10 909	10 882	10 855	10 828
28	1.198	11 316	11 291	11 267	11 242	11 217	11 192	11 167	11 142	11 116	11 091
27	1.255	11 553	11 530	11 506	11 483	11 460	11 436	11 412	11 388	11 364	11 340
26	1.313	11 777	11 756	11 734	11 711	11 689	11 667	11 644	11 622	11 599	11 576
25	1.374	11 990	11 969	11 948	11 927	11 906	11 885	11 864	11 842	11 821	11 799
24	1.436	12 190	12 170	12 151	12 131	12 111	12 091	12 071	12 051	12 031	12 010
23	1.501	12 378	12 360	12 341	12 323	12 304	12 285	12 267	12 248	12 229	12 209
22	1.568	12 554	12 537	12 520	12 503	12 485	12 468	12 450	12 432	12 414	12 396
21	1.635	12 719	12 703	12 687	12 671	12 654	12 638	12 621	12 605	12 588	12 751
20	1.705	12 871	12 857	12 842	12 827	12 812	12 797	12 781	12 766	12 750	12 734

From Figure A-1-10.5(A) the starting pressure of 228 psia (15.7 bars) (terminal pressure of main line) intersects the flow rate line (193 lb/min) (87.6 kg/min) at an equivalent length of about 300 ft (91.4 m). In other words, if the branch line started at the storage vessel, the liquid carbon dioxide would have to flow through 300 ft (91.4 m) of pipeline before the pressure drops to 228 psia (15.7 bars). This length thus becomes the starting point for the equivalent length of the branch line. The terminal pressure of the branch line is then found to be 165 psia (11.4 bars) at the point where the 193 lb/min (87.6 kg/min) flow rate line intersects the total equivalent length line of 410 ft (125 m) (300 + 110). With this new terminal pressure [165 psia (11.4 bars) and flow rate (500 lbs/min (227 kg/min)] the required equivalent nozzle area at the end of each branch line will be approximately 0.567 in.^{2} (366 mm^2). It will be noted that this is about the same as the single large nozzle example, except that the discharge rate is cut in half due to the reduced pressure.

Table A-1-10.5(c)
Values of $D^{1.25}$ and D^2 for Various Pipe Sizes

	I.D. Inches	$D^{1.25}$	D^2
½ Std.	.622	.5521	.3869
¾ Std.	.824	.785	.679
1 Std.	1.049	1.0615	1.100
1 XH	.957	.9465	.9158
1¼ Std.	1.380	1.496	1.904
1¼ XH	1.278	1.359	1.633
1½ Std.	1.610	1.813	2.592
1½ XH	1.500	1.660	2.250
2 Std.	2.067	2.475	4.272
2 XH	1.939	2.288	3.760
2½ Std.	2.469	3.09	6.096
2½ XH	2.323	2.865	5.396
3 Std.	3.068	4.06	9.413
3 XH	2.900	3.79	8.410
4 Std.	4.026	5.71	16.21
4 XH	3.826	5.34	14.64
5 Std.	5.047	7.54	25.47
5 XH	4.813	7.14	23.16
6 Std.	6.065	9.50	36.78
6 XH	5.761	8.92	33.19

The design of the piping distribution system is based on the flow rate desired at each nozzle. This in turn determines the required flow rate in the branch lines and the main pipeline. From practical experience it is possible to estimate the approximate pipe sizes required. The pressure at each nozzle can then be determined from suitable flow curves. The nozzle orifice sizes are then selected on the basis of nozzle pressure from the data given in 1-10.5.2.

In high pressure systems the main header is supplied by a number of separate cylinders. The total flow is thus divided by the number of cylinders to obtain the flow rate from each cylinder. The flow capacity of the cylinder valve and the connector to the header will vary with each manufacturer, depending on design and size. For any particular valve, dip tube and connector assembly, the equivalent length can be determined in terms of feet of standard pipe size. With this information the flow equation can be used to prepare a curve of flow rate versus pressure drop. This provides a convenient method of determining header pressure for a specific valve and connector combination.

Tables A-1-10.5(d) and A-1-10.5(e) list the equivalent lengths of pipe fittings for determining the equivalent length of piping systems. Table A-1-10.5(d) is for threaded joints and Table A-1-10 5(e) is for welded joints. Both tables were computed for Schedule 40 pipe sizes; however, for all practical purposes the same figures can also be used for Schedule 80 pipe sizes.

For nominal changes in elevation of piping the change in head pressure is negligible. However, if there is a substantial change in elevation, this factor should be taken into account. The head pressure correction per foot of elevation depends on the average line pressure where the elevation takes place since the density changes with pressure. Correction factors are given in Tables A-1-10.5(f) and A-1-10.5(g) for low pressure and high pressure systems respectively.

The correction is subtracted from the terminal pressure when the flow is upward and added to the terminal pressure when the flow is downward.

Table A-1-10.5(d) Equivalent Length in Feet of Threaded Pipe Fittings

Pipe Size in.	Elbow Std. 45°	Elbow Std. 90°	Elbow 90° Long Rad. & Tee Thru Flow	Tee Side	Union Coupling or Gate Valve
⅜	0.6	1.3	0.8	2.7	0.3
½	0.8	1.7	1.0	3.4	0.4
¾	1.0	2.2	1.4	4.5	0.5
1	1.3	2.8	1.8	5.7	0.6
1¼	1.7	3.7	2.3	7.5	0.8
1½	2.0	4.3	2.7	8.7	0.9
2	2.6	5.5	3.5	11.2	1.2
2½	3.1	6.6	4.1	13.4	1.4
3	3.8	8.2	5.1	16.6	1.8
4	5.0	10.7	6.7	21.8	2.4
5	6.3	13.4	8.4	27.4	3.0
6	7.6	16.2	10.1	32.8	3.5

Table A-1-10.5(e) Equivalent Length in Feet of Welded Pipe Fittings

Pipe Size in.	Elbow Std. 45°	Elbow Std. 90°	Elbow 90° Long Rad. & Tee Thru Flow	Tee Side	Gate Valve
⅜	0.2	0.7	0.5	1.6	0.3
½	0.3	0.8	0.7	2.1	0.4
¾	0.4	1.1	0.9	2.8	0.5
1	0.5	1.4	1.1	3.5	0.6
1¼	0.7	1.8	1.5	4.6	0.8
1½	0.8	2.1	1.7	5.4	0.9
2	1.0	2.8	2.2	6.9	1.2
2½	1.2	3.3	2.7	8.2	1.4
3	1.5	4.1	3.3	10.2	1.8
4	2.0	5.4	4.4	13.4	2.4
5	2.5	6.7	5.5	16.8	3.0
6	3.0	8.1	6.6	20.2	3.5

SI Units: 1 ft = 0.3048 m.

Table A-1-10.5(f) Elevation Correction Factors for Low Pressure Systems

Average Line Pressure psia	bar	Elevation Correction psi/ft	bar/m
300	20.7	0.443	0.100
280	19.3	0.343	0.0776
260	17.9	0.265	0.0599
240	16.5	0.207	0.0468
220	15.2	0.167	0.0378
200	13.8	0.134	0.0303
180	12.4	0.107	0.0242
160	11.0	0.085	0.0192
140	9.7	0.067	0.0152

Table A-1-10.5(g) Elevation Correction Factors for High Pressure Systems

Average Line Pressure psia	bar	Elevation Correction psi/ft	bar/m
750	51.7	0.352	0.0796
700	48.3	0.300	0.0679
650	44.8	0.255	0.0577
600	41.4	0.215	0.0486
550	37.9	0.177	0.0400
500	34.5	0.150	0.0339
450	31.0	0.125	0.0283
400	27.6	0.105	0.0238
350	24.1	0.085	0.0192
300	20.7	0.070	0.0158

A-1-11.1 Testing of Systems. Manufacturer's test and maintenance procedure should be guided by the following outline:

1. The System.
   A. Overall physical appearance.
   B. Check if there have been any changes in the size or type of hazard protected.
   C. Disarm system prior to test.
2. Supervised Circuits.
   A. Exercise all functions.
   B. Check all electrical or pneumatic supervisory circuits for proper operation.
3. Control Panel.
   A. Exercise ALL functions.
   B. Check supervision if applicable, of each circuit (including releasing devices) as recommended by the manufacturer.
4. Power Supply.
   A. Check routing, circuit breakers, fuses, disconnects.
5. Emergency Power.
   A. Battery condition.
   B. Charger operation, check fuse.
   C. Check automatic changeover.
   D. If generator, is it being properly maintained.
6. Detectors.
   A. Test each (ALL) using heat or smoke or manufacturer's approved test device. (*See NFPA 72E, Standard on Automatic Fire Detectors.*)
   B. Electric.
      1. Clean and adjust smoke detector and check sensitivity.
      2. Check wiring condition.
   C. Pneumatic.
      1. Check tightness of tubing and operation of mercury checks, using manometer.
7. Time Delay.
   A. Exercise.
   B. Check time limit.
   C. Check that timer will complete its cycle even though wiring between it and the detector circuit is interrupted.
8. Alarms.
   A. Test for operation (audible and visual).
   B. Check to see that warning signs are properly displayed.
9. Selector (Directional) Valves.
   A. Exercise.
   B. Reset properly.
10. Release Devices.
   A. Dampers, check for complete closure.
   B. Doors; also check for any blocked open.
11. Equipment Shutdown.
   A. Test.
   B. Check adequacy (all necessary equipment included).
12. Manual Releases.
   A. Mechanical.
      1. Check pull, force, and length of pull required.
      2. Operate and adjust all devices.
      3. Tightness of connectors.
      4. Condition of conduit.
      5. Condition and operation of corner pulleys.
   B. Electric.
      1. Test.
      2. Covers in place.
   C. Pneumatic releases.
   D. Accessibility during fire.
   E. Separate main and reserve manual pulls requiring only one operation to obtain discharge of either main or reserve supply of gas.
   F. Clearly mark and identify all manual releases.
13. Piping.
   A. Security, adequately supported.
   B. Condition, any corrosion.
14. Nozzles.
   A. Orientation and orifice size unchanged from original design.
   B. Clean.
   C. Security.
   D. Seals where needed.
15. Containers.
   A. Physical condition, any sign of corrosion.
   B. Check the contents for weight by acceptable methods for each cylinder or low pressure tank. If the contents are more than 10 percent below the normal capacity, refilling is required. Proper operation of the liquid level gage should be verified.
   C. Cylinders securely held in position.
   D. Check hydrostatic test record.
   E. Check cylinder connectors for integrity and condition.
   F. Check weights and cables of mechanical release system.

G. Release devices, check for proper arrangement and security.

H. Explosive release devices, check replacement date and check condition.

16. Test.

A. Discharge tests should be recommended when there is any question about the adequacy of the system. A full discharge test is required for initial accepance.

B. Full discharge test recommended when cylinder hydrostatic test is required.

17. Return all parts of system to full service.

18. Certificate of Inspection to owner.

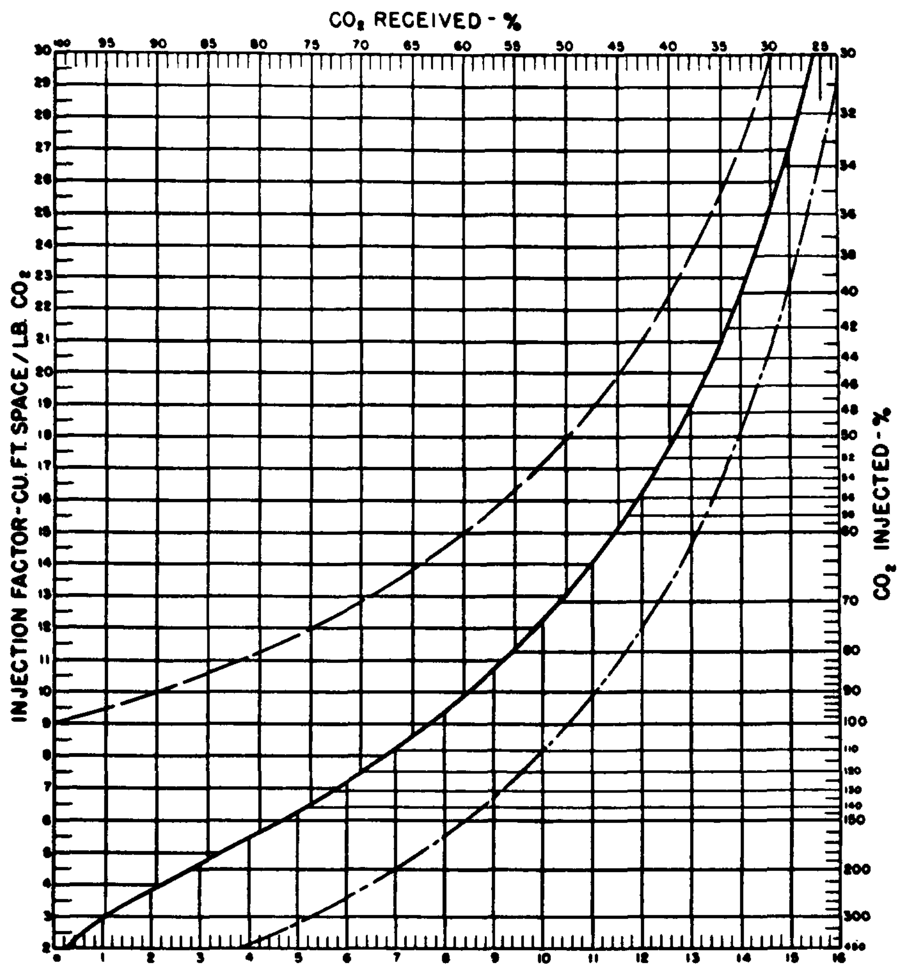
A-1-11.2 Regular service contracts with the manufacturer or installing company are recommended.

A-2-1 General Information on Total Flooding Systems.

From a performance viewpoint, a total flooding system is designed to develop a carbon dioxide concentration that will extinguish fires in combustible materials located in an enclosed space. It should also maintain an effective concentration until the maximum temperature has been reduced below the reignition point.

The concentration of carbon dioxide required will depend on the type of combustible material involved. This has been accurately determined for most surface-type fires, particularly those involving liquids and gases. Most of this information has been obtained by the US Bureau of Mines. For deep-seated fires the critical concentration required for extinguishment is less definite and has in general been established by practical test work.

The volume of carbon dioxide required to develop a given concentration will be greater than the final volume remaining in the enclosure. In most cases carbon dioxide should be applied in a manner that promotes progressive mixing of the atmosphere. The displaced atmosphere is exhausted freely from the enclosure through various small openings or through special vents, as carbon dioxide is injected. Some carbon dioxide is therefore lost with the



For SI Units: 1 ft³/lb = 0.0624 m³/kg.

Figure A-2-1(A) Carbon Dioxide Requirements for Inert Atmospheres [based on a carbon dioxide expansion of 9 ft³/lb (0.56 m³/kg)]. The top curve (complete displacement) and the bottom curve (no efflux) are theoretical extremes plotted for comparative purposes only. The middle curve (free efflux), the curve to be used, must be tempered by proper safety factors.

vented atmosphere. This loss becomes greater at high concentrations. This method of application is called "free-efflux" flooding.

Under the above conditions the volume of carbon dioxide required to develop a given concentration in the atmosphere is expressed by the following equations:

$$e^x = \frac{100}{100 - \% \; CO_2}$$

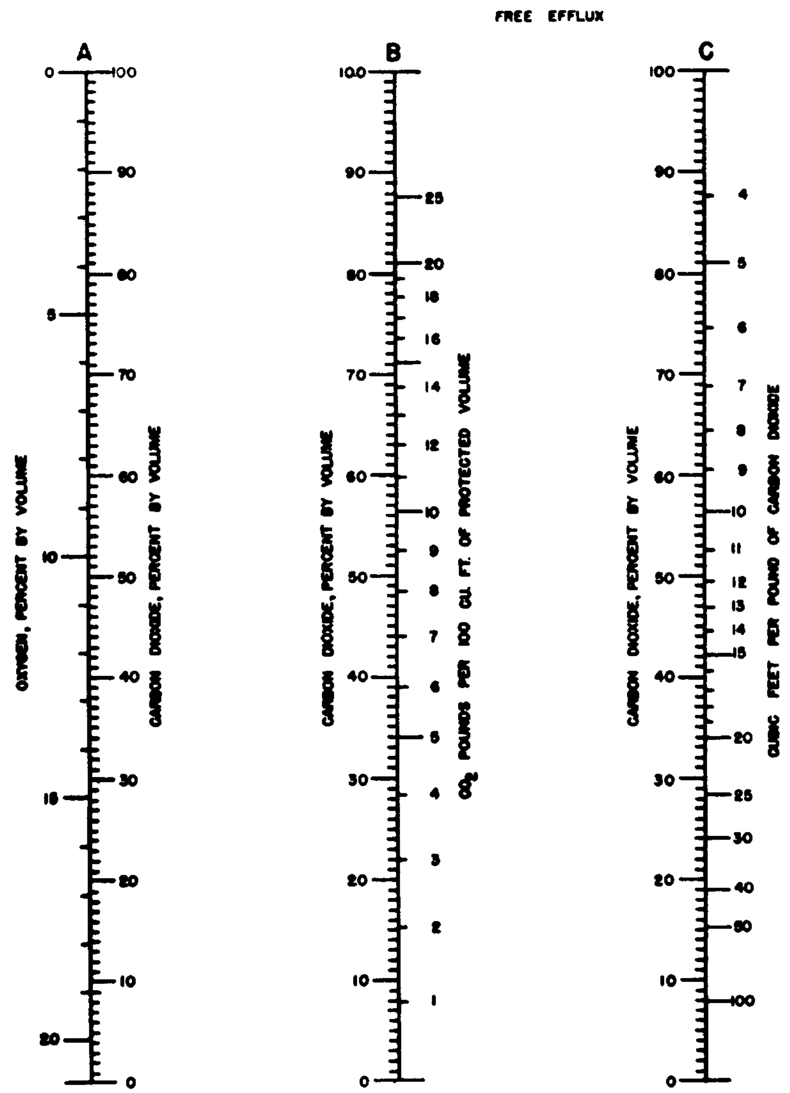
or

$$X = 2.303 \log_{10} \frac{100}{100 - \% \; CO_2}$$

In the above formula X = Volume of CO_2 added per volume of space and e = 2.718 (natural logarithm base).

From the above formula the volume of carbon dioxide required to develop a given concentration can be calculated. This quantity of carbon dioxide can be expressed in terms of cubic feet of space protected per pound of carbon dioxide or pounds of carbon dioxide per 100 ft^3. These results have been calculated and plotted for easy reference.

One such curve is shown on Figure A-2-1(A). On this curve it was assumed that the carbon dioxide would expand to a volume of 9 ft^3/lb (0.56 m^3/kg) at a temperature of 86 °F (30 °C). Similar information is also given on Figure A-2-1(B) in the form of a nomograph. In this case, it was assumed that the final temperature would be about 50 °F (10 °C), giving a volume of 8.35 ft^3/lb (0.52 m^3/kg) of carbon dioxide. The nomograph will therefore indicate somewhat greater quantities of carbon dioxide for the same concentration. The data in Chapters 1 through 5 are based on an expansion of 9 ft^3/lb (0.56 m^3/kg) of carbon dioxide. It should be noted that in some well-insulated enclo-



For SI Units
1lb/ft^3 = 16.018kg/m^3 1ft^3/lb = 0.0624m^3/kg

Figure A-2-1(B) Carbon Dioxide Requirements for Inert Atmospheres [based on a carbon dioxide expansion of 8.35 ft^3/lb (0.52 m^3/kg)]. Column A shows oxygen content of air-carbon dioxide mixtures; Column B shows weights of carbon dioxide in air-carbon dioxide mixtures; Column C shows ft^3/lb of carbon dioxide in air-carbon dioxide mixtures.

sures, such as freezers and anechoic test chambers, complete and rapid vaporization of the carbon dioxide discharge may not occur. For unusual cases like these, the manufacturer should be consulted.

The time required for cooling below the reignition point depends on the type of fire and the insulating effect of the combustible material. For surface-type fires it can be assumed that the fire will be extinguished almost as soon as the desired concentration is obtained. The enclosure should of course retain a reasonable concentration for some time after the carbon dioxide has been injected. This provides an additional factor of safety.

For deep-seated fires the concentration should be maintained for a longer period of time because the hot material will cool off slowly. The cooling time will vary considerably, depending on the nature of the material. Since the cooling time will tend to be long, it is necessary to give considerable attention to the problem of maintaining the extinguishing concentration. Surface fires and deep-seated fires are therefore basically different and should be approached with somewhat different objectives in mind.

A-2-2.3 Types of Fires. Practically all hazards that contain materials that would produce surface fires may contain varying amounts of materials that would produce deep-seated fires. Proper selection of the type of fire that the system should be designed to extinguish is important and in many cases, will require sound judgment after careful consideration of all the various factors involved.

Basically, such a decision will be based on the following:

(a) Will a deep-seated fire develop, considering the speed of detection and application of the contemplated system?

(b) If a deep-seated fire does develop, (1) will it be of a minor nature, (2) will the circumstances be such that it will not cause a reflash of the material that produced the surface fire, and (3) can arrangements be set up to put it out manually after the CO_2 discharge before it causes trouble?

(c) Are the values involved, or the importance of equipment involved, such that the ultimate protection is justified regardless of the extra cost of providing a system that will extinguish deep-seated fires?

It will be seen that with a remote possibility of a deep-seated fire causing trouble, there are many cases where taking this remote risk may be justified, and a system to extinguish surface fires may properly be selected. As an example, electrical transformers and other oil-filled electrical equipment have quite commonly been treated as producing surface fires, although there may be a chance that a heated core will produce a deep-seated fire in electrical insulation. On the other hand, the importance of some of the electrical equipment to production may be such that treating the hazard as a deep-seated fire will be justified.

Often a decision will involve consultation with the authority having jurisdiction, and with the owner and the engineers of the company supplying the equipment. The cost comparison between a system that is designed to extinguish a surface fire and one designed to extinguish a deep-seated fire may be the deciding factor. In all cases, it is advisable that all interested parties know clearly any risks involved if the system is designed to extinguish only a surface fire, and the additional costs that are involved if a system is designed to extinguish a deep-seated fire.

A-2-3 Carbon Dioxide Requirements for Surface Fires. The requirements given in Section 2-3 take into account the various factors that may affect the performance of the system. The question on limitation of unclosable openings is frequently encountered and is difficult to answer in precise terms. Since surface fires are normally of the type that can be extinguished with local application methods, a choice between total flooding or local application can be made on the basis of quantity of carbon dioxide required. This is illustrated in the following examples for the enclosure diagrammed in Figure A-2-3.

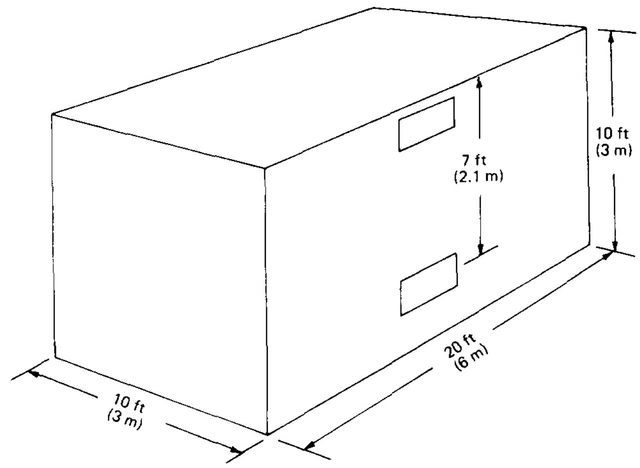


Figure A-2-3 Diagram of Enclosure for Examples 1 and 2.

Example 1

Volume of Space	2,000 ft^3
Type of Combustible	Gasoline
Ventilation Openings	
Air Outlet near ceiling	5 ft^2
Air Inlet centered @ 7 ft below ceiling	5 ft^2
Design Concentration (2-3.2.1)	34% CO_2
Volume Factor (2-3.3)	18 ft^3/lb CO_2
Basic Quantity of CO_2	$\frac{2000}{18}$ = 111 lbs

Material Conversion Factor (2-3.4) — Since the design concentration is not over 34% no conversion is needed.

Special Conditions (2-3.5) — CO_2 will be lost through the bottom opening while air enters through the top opening. From Figure A-2-5.3.3 the loss rate will be 17 lbs/min/ft^2 for a concentration of 34% at 7 feet.

Additional CO_2 for openings (2-3.5.1) = 17 × 5 = 85 lbs

Total CO_2 required = 111 + 85 = 196 lbs

Example 1 (Metric)

Volume of Space	54 m^3
Type of Combustible	Gasoline
Ventilation Openings	
Air Outlet near ceiling	0.5 m^2
Air Inlet centered @ 2.1 m below ceiling	0.5 m^2
Design Concentration (2-3.2.1)	34% CO_2
Volume Factor (2-3.3)	1.11 m^3/kg CO_2
Basic Quantity of CO_2	$\frac{54}{1.11}$ = 48.6 kg

Material Conversion Factor (2-3.4) — Since the design concentration is not over 34% no conversion is needed.

Special Conditions (2-3.5) — CO_2 will be lost through the bottom opening while air enters through the top opening. From Figure A-2-5.3.3 the loss rate will be 85 kg/min/m² for a concentration of 34% at 2.1 m.

Additional CO_2 for openings (2-3.5.1) = 85 × 0.5 = 42.5 kg

Total CO_2 required = 48.6 + 42.5 = 91.1 kg

Example 2

Volume of Space	2,000 ft³
Type of Combustible	Gasoline
Ventilation Openings	
Air Outlet near ceiling	10 ft²
Air Inlet centered @ 7 ft below ceiling	10 ft²
Design Concentration (2-3.2.1)	34% CO_2
Basic Quantity of CO_2	$\frac{2000}{18} = 111$ lbs

Additional CO_2 for openings (2-3.5.1) = 17 × 10 = 170 lbs

Total CO_2 required = 111 + 170 = 281 lbs

Since the compensation exceeds the basic flooding requirement (*see 2-2.1.1*), refer to Chapter 3. Using the rate-by-volume method, 3-5.3.1 states that the rate of discharge may be reduced to not less than .25 lbs/min/ft³ for actual walls completely surrounding the hazard enclosure. The openings can be calculated as a percent of wall enclosure to determine a proper discharge rate.

Total opening area 20 ft²

Total wall area = (10 + 10 + 20 + 20) × 10 = 600 ft²

Rate of discharge =

$$\frac{20}{600} \times (1 - .25) + .25 = 0.27 \text{ lbs/min/ft}^3$$

Total rate of discharge = .27 × 2000 = 540 lbs/min

Quantity of CO_2 = 540/2 = 270 lbs

Local application requires a liquid discharge for 30 seconds. In the case of high pressure storage, the quantity of CO_2 must be increased by 40 percent (3-3.1.1) to assure a 30-second discharge of liquid. When the openings are increased to 20 ft² each, local application techniques will require less CO_2 than total flooding for both low pressure and high pressure storage.

Example 2 (Metric)

Volume of Space	54 m³
Type of Combustible	Gasoline
Ventilation Openings	
Air Outlet near ceiling	1.0 m²
Air Inlet centered @ 2.1 m below ceiling	1.0 m²
Design Concentration (2-3.2.1)	34% CO_2
Basic Quantity of CO_2	$\frac{54}{111} = 48.6$ kg

Additional CO_2 for openings (2-3.5.1) = 85 × 1.0 = 85 kg

Total CO_2 required = 48.6 + 85 = 133.6 kg

Since the compensation exceeds the basic flooding requirement (*see 2-2.1.1*), refer to Chapter 3. Using the rate-by-volume method, 3-5.3.1 states that the rate of discharge may be reduced to not less than 4 kg/min/m³ for actual walls completely surrounding the hazard enclosure. The openings can be calculated as a percent of wall enclosure to determine a proper discharge rate.

Total opening area 2.0 m²

Total wall area = (3 + 3 + 6 + 6) × 3 = 54 m²

$$\text{Rate of Discharge} = \frac{2.0}{54} \times (16 - 4) + 4 = 4.4. \text{ kg/min/m}^3$$

Total rate of discharge = 4.4 × 54 = 237.6 kg/min/m³

Quantity of CO_2 = 237.6/2 = 118.8 kg

Local application requires a liquid discharge for 30 seconds. In the case of high pressure storage, the quantity of CO_2 must be increased by 40 percent (3-3.1.1) to assure a 30-second discharge of liquid. When the openings are increased to 2.0 m² each, local application techniques will require less CO_2 than total flooding for both low pressure and high pressure storage.

A-2-3.5.1 Where forced ventilation is not a consideration, leakage of a carbon dioxide-air mixture from an enclosed space will depend upon one or more of the following parameters:

(a) *Temperature of Enclosure.* Carbon dioxide will not expand as much at low temperature and would be more dense, thus a greater amount would leak out if the openings were in the lower portion of the enclosure.

(b) *Volume of Enclosure.* The percent of total volume of carbon dioxide lost through any given opening in a small enclosure would be much greater than that from the same opening in a large enclosure.

(c) *Venting.* An opening at or near the ceiling is usually desirable to permit exhausting the lighter gases from the room during the discharge.

(d) *Location of Openings.* Since carbon dioxide is heavier than air, there may be little or no loss of carbon dioxide from openings near the ceiling, while the loss at the floor level may be substantial.

A-2-3.5.3 Hazards located in enclosures which are normally at temperatures above 200 °F (93 °C) may be more susceptible to reignition. Therefore, additional carbon dioxide is advisable to hold the extinguishing concentrations for a longer period of time, allowing the extinguished material to cool down and thereby reduce the chances of reignition when the gas dissipates.

A-2-4.1 Although specific test data is lacking, it is recognized that certain types of deep-seated fires may require holding times in excess of 20 minutes.

A-2-5.2 Rate of Application. The minimum rates established are considered adequate respectively for the usual surface or deep-seated fire. However, where the spread of fire may be faster than normal for the type of fire, or where high values, or vital machinery or equipment are involved, rates higher than the minimums may, and in many cases should be used, and where a hazard contains material that will produce both surface and deep-seated fires, the rate of application should be at least the minimum required for surface fires. Having selected a rate suitable to the hazard, the tables and information that follow in the standard should be used or such special engineering as is required should be carried out to obtain the proper combination of container releases, supply piping, and orifice sizes that will produce this desired rate.

A-2-5.3.3 The leakage rate from an enclosure in the absence of forced ventilation depends mainly on the difference in density between the atmosphere within the enclosure and the air surrounding the enclosure. The following equation can be used to calculate the rate of CO_2 loss, assuming that there is sufficient leakage in the upper part of the enclosure to allow free ingress of air:

$$R = 60\ C\rho A\sqrt{\frac{2g\ (\rho_1-\rho_2)\ h}{\rho_1}}$$

Where R = Rate of CO_2 in lbs/min
C = CO_2 concentration fraction
ρ = Density of CO_2 vapor in lbs/ft³
A* = Area of opening in ft² (flow coefficient included)
g = Gravitational constant 32.2 ft/sec²
ρ_1 = Density of atmosphere in lbs/ft³
ρ_2 = Density of surrounding air in lbs/ft³
h = Static head between opening and top of enclosure in ft

For SI Units

$$R_M = 5.59\ C\rho_M\ A_M\sqrt{\frac{2g_M\ (\rho_{M1}-\rho_{M2})\ h_M}{_{M1}}}$$

Where R_M = Rate of CO_2 loss in kg/min
C = CO_2 concentration fraction
ρ_M = Density of CO_2 vapor in kg/m³
A_M* = Area of opening in m² (Flow coefficient included)
g_M = Gravitational constant 9.81 m/s²
ρ_{M1} = Density of atmosphere in enclosure in kg/m³
ρ_{M2} = Density of surrounding air in kg/m³
h_M = Static head between opening and top of enclosure - meter

*If there are openings in the walls only, the area of the wall openings can be divided by 2 for calculations since it is presumed that fresh air can enter through one-half of the openings and protective gas will exit through the other half.

Figure A-2-5.3.3 may be used as a guide in estimating discharge rates for extended discharge systems. The curves were calculated using the above equation assuming a temperature of 70 °F (21 °C) inside and outside of the enclosure. In an actual system the inside temperature will normally be reduced by the discharge, thus increasing the rate of loss. Because of the many variables involved, a test of the installed system may be needed to ensure proper performance.

A-2-5.3.4 For enclosed recirculating type electrical equipment, the initial discharge quantity should not be less than 1 lb of gas for each 10 ft³ (1.6kg/m³) of enclosed volume up to 2000 ft³ (56.6 m³). For larger volumes, 1 lb of gas for each 12 ft³ (1.3 m³) or a minimum of 200 lb (90.8 kg) should be used. Table A-2-5.3.4 may be used as a guide to estimate the quantity of gas needed for the extended discharge to maintain a minimum concentration of 30 percent for the deceleration time. The quantity is based on the internal volume of the machine and the deceleration time, assuming average leakage. For dampered, nonrecirculating type machines, add 35 percent to the indicated quantities in Table A-2-5.3.4 for extended discharge protection.

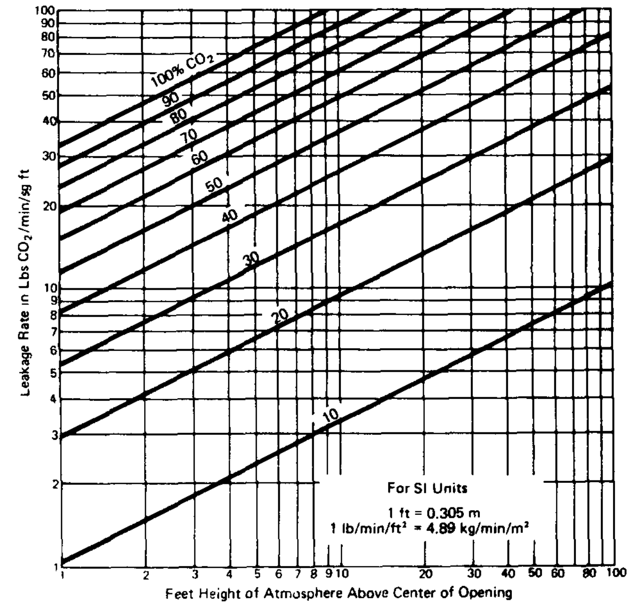


Figure A-2-5.3.3 Calculated CO_2 Loss Rate Based on an Assumed 70°F (21°C) Temperature Within the Enclosure and 70°F (21°C) Ambient Outside.

Table A-2-5.3.4 Extended Discharge Protection for Enclosed Recirculating Rotating Electrical Equipment (Cubic Feet Protected for Deceleration Time)

Lbs CO_2	5 Min.	10 Min.	15 Min.	20 Min.	30 Min.	40 Min.	50 Min.	60 Min.
100	1200	1000	800	600	500	400	300	200
150	1800	1500	1200	1000	750	600	500	400
200	2400	1950	1600	1300	1000	850	650	500
250	3300	2450	2000	1650	1300	1050	800	600
300	4600	3100	2400	2000	1650	1300	1000	700
350	6100	4100	3000	2500	2000	1650	1200	900
400	7700	5400	3800	3150	2500	2000	1600	1200
450	9250	6800	4900	4000	3100	2600	2100	1600
500	10800	8100	6100	5000	3900	3300	2800	2200
550	12300	9500	7400	6100	4900	4200	3600	3100
600	13900	10900	8600	7200	6000	5200	4500	3900
650	15400	12300	9850	8300	7050	6200	5500	4800
700	16900	13600	11100	9400	8100	7200	6400	5600
750	18500	15000	12350	10500	9150	8200	7300	6500
800	20000	16400	13600	11600	10200	9200	8200	7300
850	21500	17750	14850	12700	11300	10200	9100	8100
900	23000	19100	16100	13800	12350	11200	10050	9000
950	24600	20500	17350	14900	13400	12200	11000	9800
1000	26100	21900	18600	16000	14500	13200	11900	10700
1050	27600	23300	19900	17100	15600	14200	12850	11500
1100	29100	24600	21050	18200	16600	15200	13750	12400
1150	30600	26000	22300	19300	17700	16200	14700	13200
1200	32200	27300	23550	20400	18800	17200	15600	14100
1250	33700	28700	24800	21500	19850	18200	16500	14900
1300	35300	30100	26050	22650	20900	19200	17450	15800
1350	36800	31400	27300	23750	22000	20200	18400	16650
1400	38400	32800	28550	24900	23100	21200	19350	17500
1450	39900	34200	29800	26000	24200	22200	20300	18350
1500	41400	35600	31050	27100	25250	23200	21200	19200

Table A-2-5.3.4 (Metric) Extended Discharge for Enclosed Recirculating Rotating Electrical Equipment (Cubic Meters Protected for Deceleration Time)

kg CO_2	5 Min.	10 Min.	15 Min.	20 Min.	30 Min.	40 Min.	50 Min.	60 Min.
45.4	34.0	28.3	22.6	17.0	14.2	11.3	8.5	5.7
68.1	50.9	42.5	34.0	28.3	21.2	17.0	14.2	11.3
90.8	67.9	55.2	45.3	36.8	28.3	24.1	18.4	14.2
113.5	93.4	69.3	56.6	46.7	36.8	29.7	22.6	17.0
136.2	130.2	87.7	67.9	56.6	46.7	36.8	28.3	19.8
158.9	172.6	116.0	84.9	70.8	56.6	46.7	34.0	25.5
181.6	217.9	152.8	107.5	89.1	70.8	56.6	45.3	34.0
204.3	261.8	192.4	138.7	113.2	87.7	73.6	59.4	45.3
227.0	305.6	229.2	172.6	141.5	110.4	93.4	79.2	62.3
249.7	348.1	268.9	209.4	172.6	138.7	118.9	101.9	87.7
272.4	393.4	308.5	243.4	203.8	169.8	147.2	127.4	110.4
295.1	435.8	348.1	278.8	234.9	199.5	175.5	155.7	135.8
317.8	478.3	384.9	314.1	266.0	229.2	203.8	181.1	158.5
340.5	523.6	424.5	349.5	297.2	258.9	232.1	206.6	184.0
363.2	586.0	464.1	384.9	328.3	288.7	260.4	232.1	206.6
385.9	608.4	502.3	420.3	359.4	319.8	288.7	257.5	229.2
408.6	650.9	540.5	455.6	390.5	349.5	317.0	284.4	254.7
431.3	696.2	580.2	491.0	421.7	379.2	345.3	311.3	277.3
454.0	738.6	619.8	526.4	452.8	410.4	373.6	336.8	302.8
476.7	781.1	659.4	563.2	483.9	441.5	401.9	363.7	325.5
499.4	823.5	696.2	595.7	515.1	469.8	430.2	389.1	350.9
522.1	866.0	735.8	631.1	546.2	500.9	458.5	416.0	373.6
544.8	911.3	772.6	666.5	577.3	532.0	486.8	441.5	399.0
567.5	953.7	812.2	701.8	609.4	561.8	515.1	467.0	421.7
590.2	999.0	851.8	737.2	641.0	591.5	543.4	493.8	447.1
612.9	1041.4	888.6	772.6	672.1	622.6	571.7	520.7	471.2
635.6	1086.7	928.2	808.0	704.7	653.7	600.0	547.6	495.3
658.3	1129.2	967.9	843.3	735.8	684.9	628.3	574.5	519.3
681.0	1171.6	1007.5	878.7	766.9	713.2	656.6	600.0	543.4

A-2-5.4.1 Methods available to compensate for temperature exposures include reduced filling density for high temperature and nitrogen super-pressurization combined with reduced filling density for low temperatures. Manufacturers should be consulted for advice.

A-3-1 General Information on Local Application Systems.

A local application carbon dioxide system is designed to apply carbon dioxide directly to a fire which may occur in an area or space which essentially has no enclosure surrounding it. Such systems should be designed to deliver carbon dioxide to the hazard being protected in a manner which will cover or surround all burning or flaming surfaces with carbon dioxide during operation of the system.

The flow rate and time of application required will depend on the type of combustible material involved, the nature of the hazard (whether it is a liquid surface such as a dip tank or quench tank, or a complicated piece of machinery such as a printing press, etc.), and the location and spacing of the carbon dioxide nozzles with respect to the hazard.

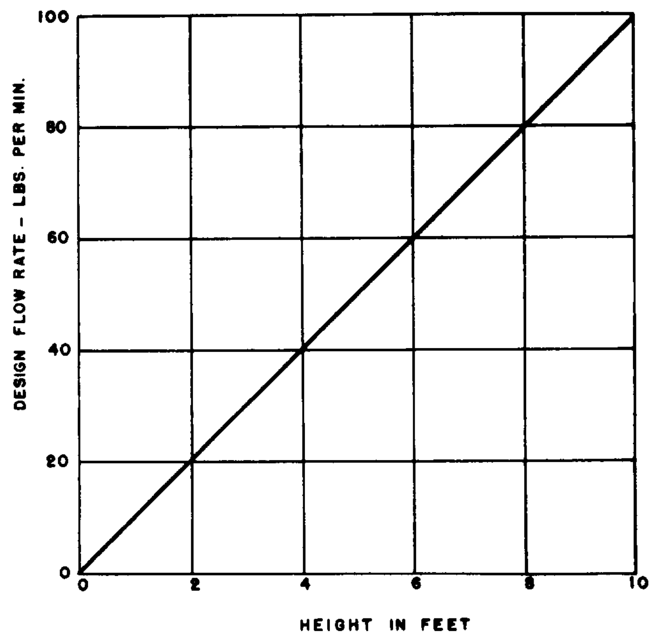
The important factors to be considered in the design of a local application system are the rate of flow, the height and area limitations of the nozzles used, the amount of carbon dioxide needed, and the piping system. The steps necessary to lay out a system are as follows:

1. Determine the area of the hazard to be protected. In determining this area, it is important to lay out, to scale, the actual hazard showing all dimensions and limitations as to placement of nozzles. The limits of the hazard should be carefully defined to include all combustibles which may be included in the hazard, and the possibility of stock or other obstructions which may be in or near the hazard should be carefully considered.

2. For overhead type nozzles, based on the height limitations of the hazard to be protected, lay out the nozzles to cover the hazard by using various nozzles within the height and area limitations which are expressed in the listings or approvals of these nozzles. The limits on area coverage of a nozzle for a particular height will be determined from listing information which is presented in a form similar to that shown by Figure A-3-1(B). In considering the area which is covered by a particular nozzle, it is important to remember that all nozzle coverage is laid out on the basis of approximate squares. Omit this step for tankside or linear type nozzles.

3. Based on the height above the hazard of each nozzle, determine the optimum flow rate at which each nozzle should discharge to extinguish the hazard being protected. This will be determined from a curve such as the one shown by Figure A-3-1(A), which will be given in the individual listings or approvals of nozzles. Omit this step and follow step 3A for tankside or linear nozzles.

3A. For tankside or linear nozzles, based on the configuration of the hazard, lay out the nozzles to cover the hazard within the spacing limitations expressed in approvals or listings. Based on the spacing or area coverage, select an appropriate flow rate from an approval or listing curve such as the one shown by Figures A-3-1(C) and A-3-1(D). Omit this step for overhead type nozzles.



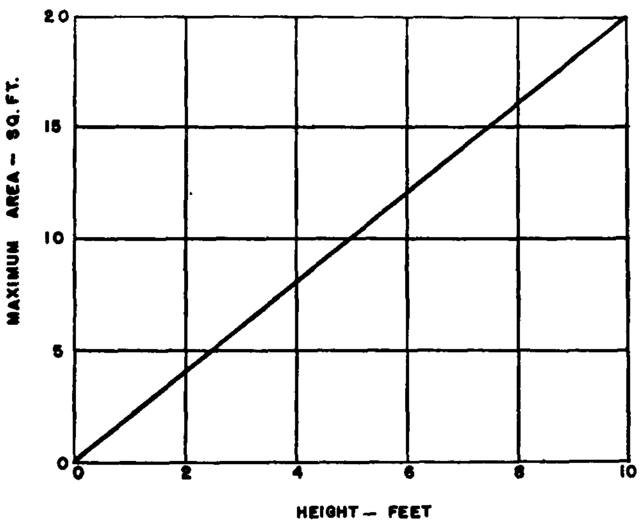
For SI Units: 1 ft = 0.305 m; 1 lb per min. = 0.454 kg/min.

Figure A-3-1(A) Listing or Approval Curve of a Typical Nozzle Showing Design Flow Rate versus Height or Distance from Liquid Surface.

4. Determine the discharge time for the hazard. This will always be a minimum of 30 seconds, but may be longer, depending on such factors as the nature of the material in the hazard and the possibility that some hot spots may require longer cooling.

5. Add up the flow rates of the individual nozzles to determine the total flow rate and multiply this by the dura-

tion of discharge to determine the total quantity of carbon dioxide needed to protect the hazard. Multiply this figure by 1.4 (for high pressure systems) to obtain total capacity of storage cylinders.



For SI Units: 1 ft = 0.305 m; 1 ft² = 0.0929 m²

Figure A-3-1(B) Listing or Approval Curve of a Typical Nozzle Showing Maximum Area versus Height or Distance from Liquid Surface.

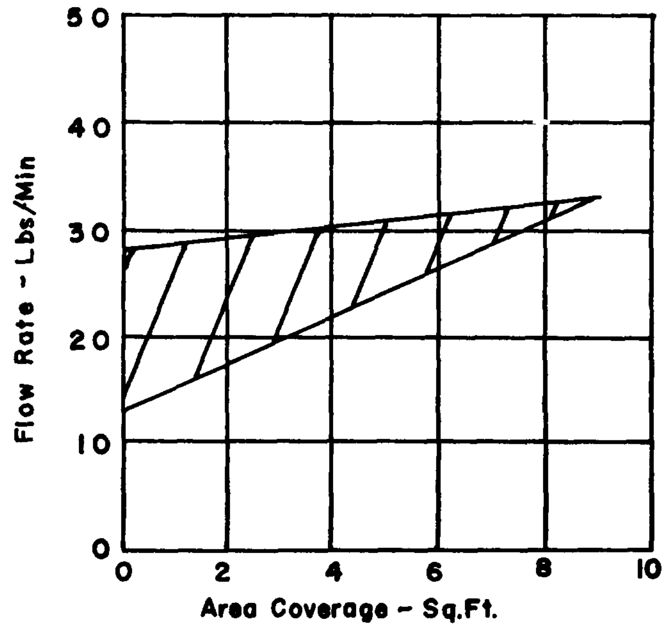
6. Locate the storage tank or cylinders and lay out the piping connecting the nozzles and storage containers.

7. Starting from the storage cylinders, compute the pressure drop through the system piping to each nozzle to obtain the terminal pressure at each nozzle (*see A-1-10.5*). Be sure to allow for equivalent lengths of pipe for various fittings and system components. Equivalent lengths of system components will be found in individual listings or approvals of these components. Assume 750 psia (51.7 bars) storage conditions for high pressure storage and 300 psia (20.7 bars) storage conditions for low pressure storage of carbon dioxide. For the initial layout it will be necessary to assume sizes of the piping at various points in the system. After going through the computations to determine the nozzle pressures, it may be necessary to adjust these pipe sizes up or down to obtain higher or lower nozzle pressures so that a proper flow rate can be achieved.

8. Based on the nozzle pressures (Item 7) and the individual nozzle flow rates (Item 3), select an equivalent orifice which comes closest to the area which produces the design flow rate by use of Tables 1-10.4(a), 1-10.4(b) and 1-10.4(c) in this standard.

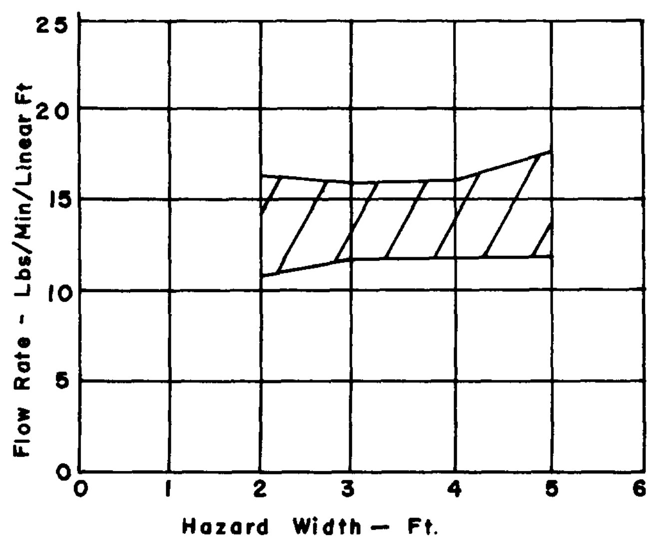
A-3-3.1 Carbon Dioxide Requirements. In computing the total quantity of carbon dioxide required for a local application system, the total flow rate for all nozzles should be added together to obtain the mass flow rate for protection of the particular hazard. This rate should be multiplied by the discharge time.

A-3-3.1.1 High Pressure Storage Cylinders. These are normally rated in nominal capacities of 50, 75, and 100 lb (22.7, 34.1, and 45.4 kg) of carbon dioxide. When the



For SI Units: 1 ft² = 0.0929 m²; 1 lb/min. = 0.454 kg/min.

Figure A-3-1(C) Typical Listing or Approval Curve of a Tankside Nozzle Showing Flow Rate versus Area Coverage.



For SI Units: 1 ft = 0.305 m; 1 lb/min./ft. = 1.49 kg/min/m

Figure A-3-1(D) Typical Listing or Approval Curve of a Linear Nozzle Showing Flow Rate versus Hazard Width.

cylinders are filled with carbon dioxide at a normal filling density not in excess of 68 percent, a portion of the discharge from the cylinders will be as liquid carbon dioxide and the remainder will be as vapor. For design purposes, the vapor discharge is considered to be ineffective in extinguishing a fire. It has been found that the amount of carbon dioxide which is discharged from the nozzle as liquid carbon dioxide varies from 70 to 75 percent of the total quantity of carbon dioxide contained in the cylinder, and thus it is necessary to increase the nominal cylinder capacity for a given system by 40 percent to account for the vapor portion of the carbon dioxide. For example, a 50-lb (22.7-kg) cylinder may be expected to discharge between 35 and 37.5 lb (15.9 and 17.0 kg) of carbon dioxide as liquid which is the part of the discharge which is effective in fire extinguishment.

A-3-3.1.2 When liquid carbon dioxide flows through a warm pipeline, the liquid will evaporate rapidly until the pipeline has been cooled to the saturation temperature of the CO_2. The quantity of carbon dioxide liquid evaporated in this manner depends on the total amount of heat that should be removed from the pipeline and the latent heat of evaporation of the CO_2. For high pressure carbon dioxide the latent heat of evaporation will be about 64 Btu/lb (149 kJ/kg), and for low pressure carbon dioxide the latent heat of evaporation will be about 120 Btu/lb (279 kJ/kg).

The quantity of heat to be removed from the pipeline is the product of the weight of the pipeline times the specific heat of the metal times the average temperature change of the pipeline. For steel pipe the average specific heat will be about 0.11 Btu per lb per degree Fahrenheit (0.46J/kg.K) temperature change. The average temperature change will be the difference between the temperature at the beginning of the discharge and the average temperature of the liquid flowing through the pipe. For high pressure CO_2 the average temperature of the liquid in the pipeline can be assumed to be about 60 °F (16 °C). For low pressure CO_2 the average temperature can be assumed to be about −5 °F (−21 °C). These temperatures would of course vary somewhat in accordance with average nozzle pressures; however, such minor adjustments would not substantially affect the results. The following equation can be used to compute the quantity of CO_2 evaporated in the pipeline.

$$W = \frac{w\ Cp\ (T_1 - T_2)}{H}$$

Where W = Pounds of CO_2 evaporated
w = Weight of piping in pounds
Cp = Specific heat of metal in pipe (0.11 for steel)
T_1 = Average pipe temperature in °F before discharge
T_2 = Average CO_2 temperature in °F
H = Latent heat of evaporation of liquid CO_2 in Btu/lb

For SI Units

$$\omega_M = \frac{4.19 W_M\ Cp\ (T_{1M} - T_{2M})}{H_M}$$

ω_M = kg of CO_2 evaporated
w_M = Weight of piping in kg
Cp = Specific heat of metal in pipe (0.11 for steel)
T_{1M} = Average pipe temperature in °C before discharge
T_{2M} = Average CO_2 temperature in °C
H = Latent heat of evaporation of liquid CO_2 in kJ/kg

A-3-3.3 Duration of Discharge. Since the tests conducted in the listing or approvals of carbon dioxide nozzles will require that fires be extinguished within a maximum time limit of 20 seconds, a minimum duration of 30 seconds has been established for this standard. This allows a factor of safety for conditions which may be unpredictable. It is important to recognize that this discharge time is a minimum and that conditions such as high temperatures and cooling of unusually hot surfaces within the hazard area may require an increase in the discharge time to assure complete and effective extinguishment.

A-3-3.3.2 The maximum temperature of a burning liquid fuel is limited by its boiling point where evaporative cooling matches the heat input. In most liquids the autoignition temperature is far above the boiling temperature so that reignition after extinguishment can be caused only by an external ignition source. However, there are a few unique liquids that have autoignition temperatures much lower than their boiling temperatures. Common cooking oils and melted paraffin wax have this property. To prevent reignition in these materials it is necessary to maintain an extinguishing atmosphere until the fuel has cooled below its autoignition temperature. A discharge time of 3 minutes is adequate for small units, but a longer time may be needed for larger capacity units.

A-3-4.2.1 In the individual listings or approvals of overhead type nozzles, tests are conducted to determine the optimum design flow rate at which a nozzle should be used for the height at which it is installed above a liquid surface. The tests are conducted in the following manner:

Fire tests of overhead type nozzles are conducted to develop a curve relating maximum flow rate at which a nozzle can be used at various heights. Testing at a number of heights establishes a splash curve which can be plotted as a straight-line function of height vs. flow rate. In conducting these tests, the flow rates used are computed on the basis of high pressure storage conditions of 70 °F (21 °C) [average pressure 750 psia (51.7 bars)] and low pressure storage conditions of 0 °F (−18 °C) [300 psia (20.7 bars)]. In the case of the high pressure tests, the fire tests are conducted with the cylinders conditioned at a temperature of 120 °F (49 °C) which gives a flow rate somewhat higher than the computed flow rate.

Following this, a minimum flow rate for various heights is assumed at a computed flow rate which is 75 percent of the maximum flow rate previously established. Again, a straight-line curve can be plotted of flow rate vs. height.

Following this, tests are conducted in which the area of the fire is varied to determine the maximum area which can be extinguished by a particular nozzle at various heights when applied at a flow rate equal to 75 percent of the maximum flow rate. In conducting these tests for high pressure storage cylinders, the flow rates for the various fires are computed on the basis of 70 °F (21 °C) [750 psia (5.7 bars) storage] and the test cylinders are conditioned to a temperature of 32 °F (0 °C).

From these data, two curves are plotted: the first is a flow rate vs. height curve, and the second is an area vs. height curve. The final plot of the flow rate vs. height curve shows a single curve established at a flow rate which is 90 percent of the maximum flow rate. It is then possible to utilize this nozzle for various heights at the design flow rate indicated by this curve, or at flow rates slightly above or below this curve to allow for differences between computed and actual rates. Typical curves are shown in Figures A-3-1(A) and A-3-1(B).

Since these curves are developed on the basis of fire tests